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The Public Benefit of Energy Efficiency to the State of Washington

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PREFACE

This report assesses the benefits of energy efficiency to the Washington state economy, its environment, and its citizens. Because energy efficiency and its effects are difficult to measure directly, this analysis estimates energy efficiency through its effects on energy consumption and economic productivity (i.e., energy intensity), while controlling for price, sectoral composition, and other factors. Further, this study is limited to improvements in the use of energy in the industrial, commercial, and residential sectors and does not include, for example the transportation sector. Conceivably, improvements in energy usage in these sectors could yield a number of benefits, including economic gains, improved productivity, improved quality of service, higher reliability, reduced pollution, and lower costs to consumers. This report addresses three of these benefits:

- Effects on the gross state product of energy efficiency improvements in the commercial and industrial sectors;

- Effects on air emissions of the improved utilization of energy in the commercial and industrial sectors; and

- Effects on households, particularly low-income households, of improvements in residential energy efficiency.

State audits have concluded that government investments in energy efficiency programs have affected energy intensity (the energy consumed per unit of output) in Washington, but this study does not establish this link; this study is limited in its ability to directly compare energy efficiency programs to actual improvements in energy efficiency.

The Energy Foundation, a partnership of major foundations interested in sustainable energy, funded this study[1]. The results are intended to inform policymakers and the general public about the benefits of energy efficiency programs in the state, to help these readers to understand the role of the government in promoting these programs,

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[1] See http://www.ef.org/

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and to provide useful information for national and local policymakers when they consider funding for energy efficiency programs in the future.

The authors would like to thank those individuals and organizations who helped in the researching and preparation of the report. A partial listing includes Arne Olson and Liz Klumpp of the Washington State Office of Trade and Economic Development (OTED)[2]; Tom Eckman of the Northwest Power Planning Council (NPPC)[3]; and RAND's internal and external reviewers of the report.

This research was performed by members of the Energy Strategy Group within RAND Science and Technology. RAND is a non-profit, non-partisan research organization[4]. For further information on this report, please contact Mark Bernstein (markb@rand.org).

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[2] See http://www.oted.wa.gov/
[3] See http://www.nwcouncil.org/
[4] See http://www.rand.org

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FIGURES

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ACRONYMS

aMW	Average Megawatt (Annual)
AEE	Autonomous Energy Efficiency
CO	Carbon Monoxide
CPI	Consumer Price Index
DOE	U.S. Department of Energy
DSM	Demand Side Management
EIA	U.S. Department of Energy, Energy Information Administration
EPRI	Electric Power Research Institute
FPL	Federal Poverty Level
GWh	Gigawatt-hour
GSP	Gross State Product
LBL	Lawrence Berkeley National Laboratory
LIHEAP	Low-Income Home Energy Assistance Program
OFM	Washington State Office of Financial Management
ORNL	Oak Ridge National Laboratory
OTED	Washington State Office of Trade and Economic Development
NCLC	National Consumer Law Center
NERC	North American Electric Reliability Council
NOX	Nitrogen Oxides
NPPC	Northwest Power Planning Council
NWPP	Northwest Power Pool
PPI	Producer Price Index
RECS	Residential Energy Consumption Survey
SIC	Standard Industrial Classification
SO2	Sulfur Dioxide
SOX	Sulfur Oxides
WAP	Weatherization Assistance Program
WDOE	Washington State Department of Ecology
WOCD	Washington State Office of Community Development
WSCC	Western Systems Coordinating Council

EXECUTIVE SUMMARY

RAND, a non-profit and non-partisan research organization, has prepared this report with funding from the Energy Foundation, a partnership of major foundations interested in sustainable energy.

In this study, we estimate energy efficiency from measures of energy intensity that have been controlled for sectoral composition, energy prices and other factors. In this report we address the public benefits of our estimate of energy efficiency to Washington and find that improvements in energy efficiency in the commercial, industrial and residential sectors are associated with:

- A benefit to the state economy since 1977 that ranges from $819 per capita to $1,120 per capita in 1998 dollars[5].

- Approximately 20 percent lower air emissions from stationary sources in Washington's share of emissions from power in the western U.S.

- A reduced energy burden on low-income households, particularly in the eastern part of Washington.

This study measures the benefit to the state economy of improvements in energy efficiency in the industrial and commercial sectors from 1977 to 1997. It also predicts the potential future impacts of continued improvements in energy efficiency.

There are four key issues and assumptions in this paper:

- This is an analysis that shows that declines in energy intensity (the energy consumed per unit of output) are associated with increases in GSP (gross state product) holding sectoral composition, energy prices, and other factors constant.

- When these other factors are held constant, changes in energy intensity can be an approximation of changes in energy efficiency. Thus, the conclusion is that improvements in energy efficiency are associated with improvements in gross state product.

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[5] Except where otherwise noted, economic variables are deflated according to the Producer Price Index for Finished Goods, with base year 1982, and expressed in 1998 dollars (1998$).

- Government investments in energy efficiency programs may lead to improvements in GSP. But, at this point we don't know how government programs affect the overall energy efficiency as used in the GSP analysis.

- Estimates of the cost per kWh saved of efficiency programs are compared to changes in GSP due to improvements in energy efficiency. These comparisons are for information purposes and we do not assume that energy efficiency programs translate one-for-one into overall improvements in energy efficiency.

Impacts on the State Economy

In this study, GSP per capita is our indicator of economic performance. The GSP measures the value of outputs from all economic sectors in the state. GSP per capita in Washington grew by 62 percent from 1977 to 1997. The growth in GSP is due to a variety of factors, including but not limited to the industrial composition of the state, the growth of industry output, growth of commercial establishments, and demographic changes in the state. We use a conventional economic approach to measuring the growth in GSP per capita, in which state economic growth is correlated with the stock and flow of capital and labor, government policies, and the characteristics of the population.

We hypothesize that changes in energy intensity—the energy consumed per unit of output—have also had an effect on the growth of GSP per capita. And by controlling for various exogenous factors such as price, industrial mix, new capital, and climate, we attempt to capture changes in energy intensity associated with energy efficiency that has resulted partly from changes in government policy.

Energy efficiency in Washington: 1977- 1997

The energy intensity of the industrial and commercial sectors in the state has declined considerably, though not consistently, since 1977. Despite the rapid increase in Washington's total energy consumption during that period, energy consumption per dollar of GSP declined by 28 percent over the period (OTED 2001). The contributing factors to these changes are many. In the industrial sector, for example, the composition of the industrial sector has changed: the concentration of energy intensive industries in the state (e.g., aluminum, and pulp and paper processing) has declined, and this decline reduces the aggregate amount of energy used per unit of output. Increases in the price of

energy from the late 1970s to the mid 1980s, and the resulting decline in the demand for energy, contributed to the declines in energy intensity as well. New technologies and Washington's building energy code also support declines in energy intensity.
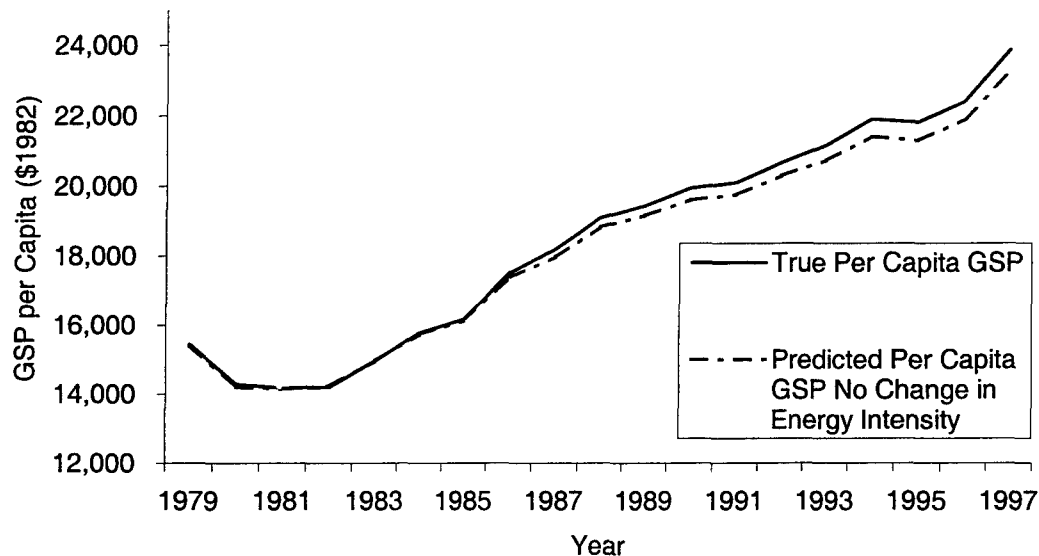
Figure S.1. Actual GSP per capita from
1979 to 1997 and GSP per capita in the case
of constant energy intensity.

Our model includes controls for exogenous factors such as the composition of industry, energy prices, and others in order to more fully isolate the improvements in energy intensity due to energy efficiency. The model indicates that when controlling for those factors, if there had been no improvement in energy intensity from 1977 to 1997 the Washington economy would have been nearly three percent smaller than it was in 1997. In other words, the benefit in 1997 to the Washington economy from improvements in industrial and commercial energy intensity since 1977 ranges from $819 per capita to $1,120 per capita. These changes in energy intensity that are associated with economic growth in the state were independent of the exogenous factors named above. These changes may be the effect of government policy in the form of energy efficiency programs. In order to draw a more solid conclusion, we need better data for national

demand side management (DSM) expenditures. Absent this information, we take an indirect approach in evaluating these programs.

Beginning in 1979, the region saw implementation of a wide variety of energy efficiency programs. Bonneville Power Administration (BPA), which supplies approximately 45 percent of the electricity used in the Northwest, reports spending $1.75 billion to achieve savings of 725 average MW (aMW) from 1982 to 1998. This savings reported by BPA alone equates to a 2.5 percent reduction of the region's winter peak demand, more than 7 percent of total generation, and nearly enough energy to supply all of Seattle for one year. Detailed utility investment data from 1977 to 1997, however, are incomplete. From 1990 to 1994—a period during which utilities invested heavily in conservation programs—Washington utilities spent a cumulative total of $744 million (assuming a 5 percent discount rate), saving nearly 350 aMW of power by investment over this period alone (OTED 2001). Audits of the energy efficiency programs have verified that energy efficiency improvements are real and contribute to reductions in energy intensity. Through 2001, total BPA and Washington utility investments in energy efficiency have generally declined to less than one-third their 1993 level.

Energy efficiency and the state economy: 2000-2015

Historically, Washington has enjoyed ample, cheap power provided primarily by its extensive system of hydroelectric dams. Population growth over the past 20 years has increased demand for new energy supplies and has inspired investment in conservation programs. Washington has achieved significant benefits from reductions in energy intensity since the late 1970s, but the future of energy use and energy efficiency programs in the state is uncertain. As in the 1980s and 1990s, demographic projections predict that the state's greatest population growth will be in western Washington, but at a slower rate than that of the past 20 years (OFM 2001). Although eastern Washington is mostly rural and supports only 20 percent of the state's population, cooling and heating loads are greater; thus, businesses and residences located in these areas will operate at higher energy intensity than comparable businesses and residences located in more temperate areas in the western part of the state. Lower energy prices in the long term, use of new electronic household and office appliances, and an increased load on space

conditioning could lead to increased energy intensity in all sectors. Washington's energy connection to other states via the Western grid also connects the state to the region's demand and reliability problems as well.

The analysis shows that after controlling for various factors, reduced energy intensity does have an impact on economic growth. Energy intensity in the industrial and commercial sectors in Washington declined overall from 1977 to 1997. In the period from 1977 to 1985, energy intensity increased, followed by a decrease in energy intensity from 1986 to 1995. Looking to the future, if energy intensity were to increase at the 1977 to 1985 rate, GSP per capita in 2015 could be $420 per capita less than it would have been if energy intensity remained at its 1997 level. On the other hand, if energy intensity were to decline at the overall 1977 to 1997 rate, the benefit to GSP in 2015 could be approximately $537 per capita. If energy intensity were to decline at the 1985 to 1997 rate, the benefit to GSP per capita could be approximately $1,104 per capita. Thus, continued declines in energy intensity, after controlling for various factors, could continue to benefit the state economy. However, our economic methodology cautions us to interpret these estimates of the benefits of reduced energy intensity as upper bounds.

Environmental Benefits

One of many environmental benefits associated with improved energy efficiency is the effect on air emissions. In our analysis, we find that if energy intensity in the state had remained at 1977 levels, air emissions as a result of Washington's power consumption could be approximately 20 percent greater than current levels. Washington receives its power from various sources in the west; hence the reductions in emissions are spread over the western region. Mobile sources are the primary contributors to air emissions and the transportation sector has grown dramatically over the past 20 years, yet reductions in energy intensity in the commercial and industrial sectors have allowed Washington to slow the growth of emissions despite increases in energy consumption throughout the state.
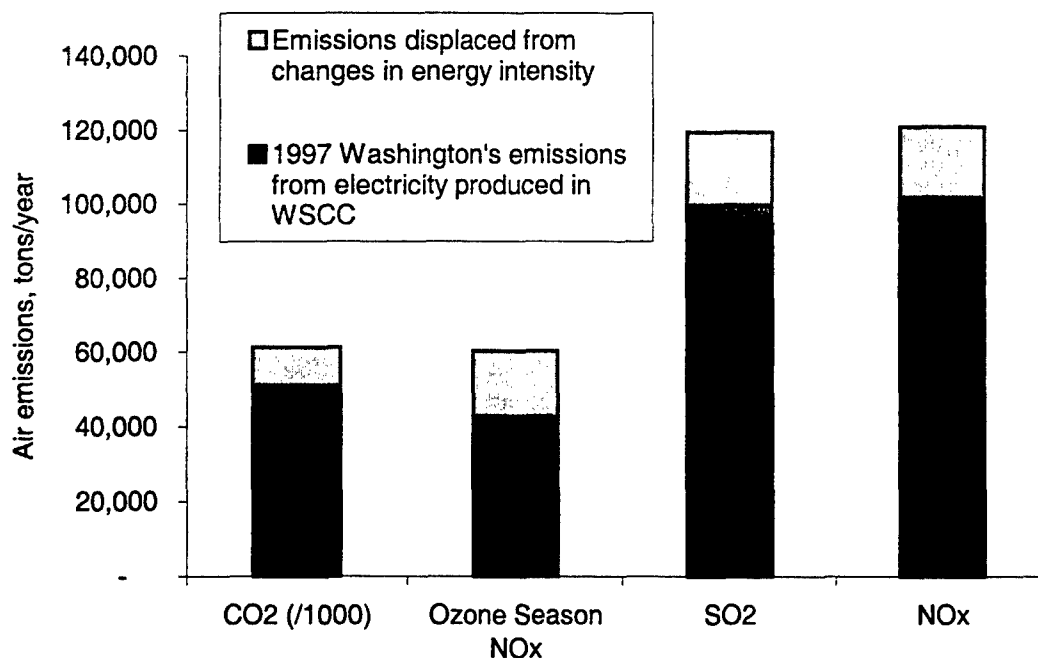
Figure S.2. Emission reductions in
Washington from electricity produced in the
WSCC (WDOE 1999).

Benefits to the Citizens

Unlike energy intensity and GSP in the industrial and commercial sectors, there is
no easily quantifiable parameter with which to evaluate the benefits of energy efficiency
to the residential sector. Furthermore, the economic benefits of reduced energy
consumption in the residential sector are uncertain: modest increases in disposable
income may not manifest themselves as large-scale economic benefits to the state. It is
clear, however, that investments in energy efficiency do reduce household energy costs
and these investments are cost-effective. In Washington, improvements in residential
energy intensity and energy prices have reduced the average energy expenditures per
capita in real terms from a peak of $512 in 1983 to $380 in 1997. These are benefits to
Washington residents.

Energy efficiency has the potential to reduce household energy costs across all
income levels (Figure S.3), but low-income households derive the greatest benefit from
reduced energy expenditures. While low-income households spend less on energy than
higher income households, the burden as a percent of income is much higher for lower

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income populations. Thus, reduced energy costs in lower income households increase disposable income at a higher rate than in higher income households.
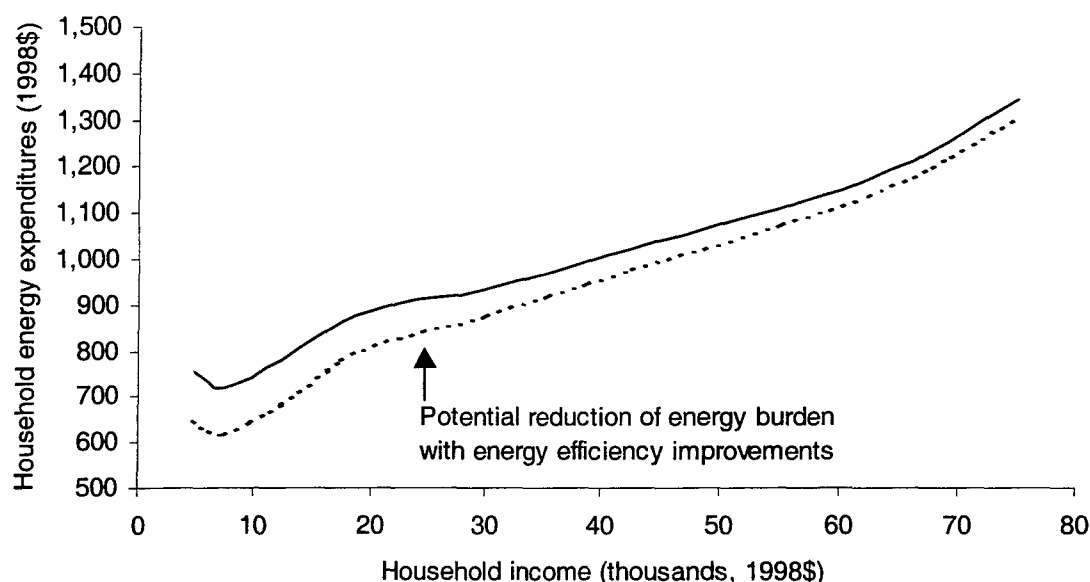
Figure S.3. Annual Washington household
energy expenditure (EIA 1997).

On average, low-income households nationwide spend eight percent of their income on electricity, compared with two percent of a median-income household. In very poor households—those below 50 percent of the federal poverty level—23 percent of household income may be spent on electricity. Most of the energy-related services provided to these households are low quality, using inefficient appliances and inadequate heating and cooling. A 1993 survey found that low-income households spend more for water heating than median income households and spend almost as much on space heating, even though low-income homes are 40 percent smaller in size.

The opportunities for energy efficiency in the household can provide very direct benefits for low-income consumers. Energy efficiency programs at the household level provide two services: (1) they directly reduce monthly energy costs, thereby increasing the disposable income of the population (and consequently increasing the disposable income of the low-income population by a greater percent than high-income households),

and (2) they improve quality of life by improving the comfort level in homes. There are few government programs that can achieve both these goals.

Yet, federal LIHEAP (Low-Income Home Energy Assistance Program) allocations have declined by more than half since the mid-1980s, and do not fully serve the targeted low-income population. Recent energy price shocks have created new political support for LIHEAP funding—Washington's share increased to $21.9 million in 2000 and $28.1 million in 2001—but current levels still covered only 17 percent of the state's eligible population in the 2000 program year (WOCD 2001).

Conclusions

Declines in energy intensity have been associated with increased economic growth, improved air quality, and direct benefits to Washington residents. Conversely, future increases in energy intensity could reverse these achievements. While these declines have coincided with investments in energy efficiency, we do not specifically evaluate the link between energy efficiency programs and improvements in energy intensity.

CHAPTER ONE
INTRODUCTION

Background

Historically, hydropower provided clean, ample and low-priced electricity to Washington residents. With economic development of the region, however, the growing demand for electricity in Washington has exceeded the supply of this once surplus energy source. As shown in Figure 1.1, total hydroelectric production has flattened over the past 20 years while total electricity consumption continued to climb (fluctuations in generation are due primarily to variation in rainfall; increased output in the early 1980s, 1990 and 1995-1997 can be correlated with above average precipitation in those years.)
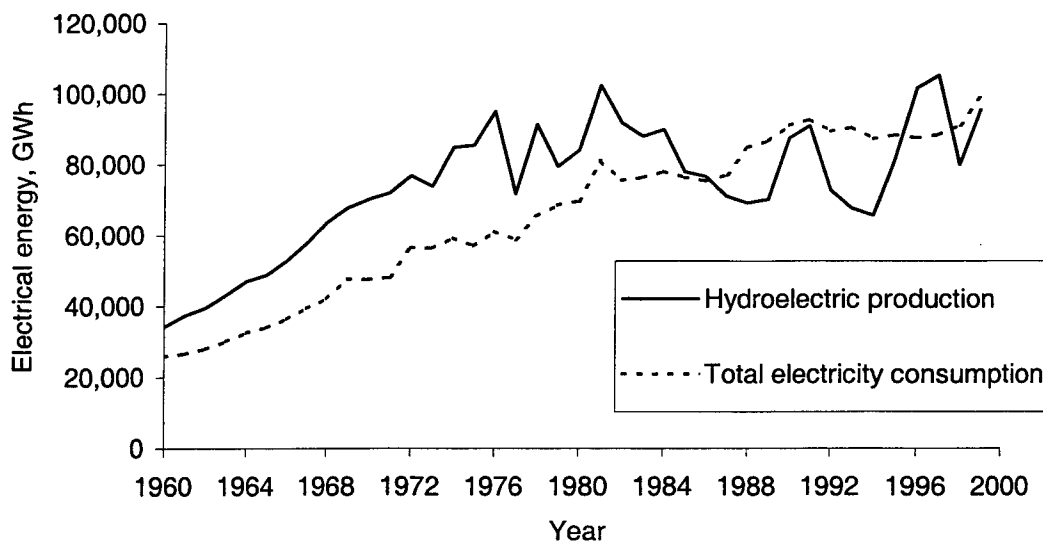
Figure 1.1. Washington hydroelectric production
and total electricity consumption: 1960 to 1999 (EIA 1999).

Though Washington continues to rely heavily on hydroelectric generation, its relative contribution to the state's total energy supply has declined since the mid-1980s, and no new hydropower opportunities exist. Thus, more expensive thermal generation resources—notably coal, nuclear fission, and natural gas—have added to the state's fuel mix since the 1970s. But various economic and environmental challenges over the past

20 years have led to a number of planning statutes and rules that have required utilities to consider not only supply-side alternatives for meeting new demand, but also demand-side management (DSM) options including energy efficiency. As such, energy efficiency has become recognized as another viable source of supply, with energy efficiency investments often providing energy services equivalent to new power plants, but at lower economic and environmental cost.

The history of state conservation and energy efficiency legislation in Washington dates back to 1931, with the Revised Code of Washington (RCW) setting forth the purpose of public utility districts to conserve water and power resources for the benefit of state residents. Similar policy objectives were established through the state building code, and for various state and local agencies and programs, including Washington's clean air and solid waste programs and low-income weatherization programs.

In 1991, the Legislature instructed the Governor to appoint a group of 20 citizens— representatives of business and industry, and public officials—to develop a strategy to assure adequate, economical, and reliable energy while protecting the environment and promoting economic development. In 1994, the Legislature enacted ESB 6493, making Washington's Energy Strategy the primary guidance for implementation of the state's energy policy, and Governor Lowry implemented the Washington Energy Strategy by executive order.

Several federal laws have provided guidance in conservation and energy efficiency in Washington over the past 20 years as well. These laws include the National Energy Act (1978), the Public Utility Regulatory Policies Act (PURPA, 1978), The Pacific Northwest Electric Power Planning and Conservation Act (the Regional Act, 1980), the National Appliance Energy Conservation Act (1987), and the National Energy Policy Act (1992). The Regional Act includes conservation and renewable resource planning among its primary purposes; under its direction, the Bonneville Power Administration (BPA) has worked with customers and stakeholders to design and fund energy efficiency and renewable energy programs through the mid 1990s.

BPA reports that between 1980 and 1999 over $1.75 billion was invested in conservation programs, gaining almost 750 annual average megawatts (aMW) of power. Indeed, BPA has accounted for a large part of investment in energy efficiency in the

state, ranging from 36 percent to 51 percent of total investment from 1990 to 1998 (WUTC 1998). Yet, total Washington utility investments in energy efficiency programs have dropped from $155 million in 1993 to $37 million in 1999 (OTED 2001). Decreased investments since the mid 1990s are likely due to a drop in the cost of power, and the uncertainty surrounding electricity restructuring. In a traditional, fully regulated environment, utilities could recover the reasonable costs of conservation investments through rates. Even though Washington has not deregulated its retail electricity markets, the perceived need of utilities to position themselves more competitively may have reduced their incentives to invest in conservation.

Recent (2001) bills in the state legislature—HB 1840, and its companion bill SB 5867—propose to restore investments in energy conservation, renewable energy resources, and low-income energy services by establishing investment standards: Three percent of the total annual revenues from retail electricity sales in Washington would be dedicated to investments in energy conservation, renewable energy research and development, and low-income energy services. Three percent of total 1998 retail sales would amount to approximately $110 million, which is comparable to the level of electricity efficiency investment of the early 1990s in Washington. Furthermore, at least two percent of the total annual revenues from retail natural gas sales in Washington would be dedicated to investments in energy conservation and low-income energy services. Investment funds would be collected via a non-bypassable, competitively neutral system benefits charge. These bills also propose adoption of a performance standard requiring that a minimum amount of non-hydroelectric renewable energy must be included in the portfolio of electricity resources serving the state; the amount would increase from five percent in 2003 to 20 percent after 2015.

Research Approach

In this report, we will assess the public benefits that accrue from improvements in energy efficiency, and evaluate past and potential future benefits to Washington's economy, its environment, and its citizens. Note, however, that energy efficiency can take on two complementary notions: An energy efficient appliance in a home, for example, can use less energy to provide the same level of service, or it can use the same

amount of energy to provide an increased level of service. In the first case, less energy is used and the reduction can be measured directly. In the second case, the same amount of energy is used and to characterize the increase in efficiency requires a measure of comfort or utility—characteristics that elude succinct and accurate definition and measurement. Energy efficiency then is a difficult metric to use directly.

In this report, we use measures of energy intensity as a proxy for energy efficiency. Defined broadly, energy intensity is the energy used per unit of output or unit served. An economy-wide indicator of energy intensity may be the energy per gross state product. In the commercial sector, where the primary energy load is for lighting and space conditioning, an appropriate measure of energy intensity may be the energy use per square foot, perhaps accounting for occupancy and employee hours. In both these examples, changes in energy intensity reflect inverse changes in energy efficiency: when energy intensity decreases, energy efficiency increases. However, a change in energy intensity does not necessarily reflect a change in energy efficiency. In the industrial sector, for instance, a change in energy use per dollar of gross state product may be due to changes in the mix of industries in the state or an increase in the price of energy rather than the investment in new equipment or energy efficient technologies. Energy efficiency, in this context, is defined as those changes in energy intensity in the industrial and commercial sectors that are not due to economic or sectoral factors such as energy price, capital investment and climate.

The approach used in this study follows that of a previous RAND study for the California Energy Commission that examined the public benefit of energy efficiency to the state of California (Bernstein et al 2000). Similarly, our analysis here adopts a macroeconomic view of the Washington economy with commercial and industrial energy intensity as key independent variables, and gross state product (GSP) as the dependent variable. We attempt to control for several potentially confounding factors such as price, industrial mix, new capital, and climate. The empirical specification and results for Washington are detailed elsewhere (Bernstein et al 2000). However, additional research is necessary to evaluate the validity of the underlying assumptions and the robustness of the economic analysis to modeling error.

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A second aspect of our analysis quantifies the effect of reduced energy intensity in the commercial and industrial sectors on air quality in Washington.

In addition to our analysis of GSP improvements due to energy efficiency (i.e., energy intensity that has been controlled for various factors) in the commercial and industrial sectors, we examine energy efficiency benefits in the residential sector, which accounts for approximately 15 percent of the state's energy use. Unlike the commercial and industrial sectors, the value of energy efficiency to the residential sector is not directly quantifiable. Therefore, we examine a number of benefits to Washington households due to energy efficiency including financial savings, increased comfort and increased energy services. We focus our analysis of the residential sector on low-income households due to their disproportionate energy burden relative to income level.

While the transportation sector also accounts for a large, and increasing portion of energy consumption in Washington, analysis of energy use in the transportation sector is beyond the scope of this study.

Together, these three analyses provide useful evidence for determining the value of energy efficiency to Washington.

In summary, there are four key issues and assumptions in this paper:

- This is an analysis that shows that declines in energy intensity are associated with increases in GSP when sectoral composition, energy prices, and other factors remain constant.
- When these other factors are held constant, changes in energy intensity can be an approximation of changes in energy efficiency. Thus, the conclusion is that improvements in energy efficiency are associated with improvements in gross state product.
- Government investments in energy efficiency programs may lead to improvements in GSP. But, at this point we don't know how government programs affect the overall energy efficiency as used in the GSP analysis.
- Estimates of the cost per kWh saved of efficiency programs are compared to changes in GSP due to improvements in energy efficiency. These comparisons

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are for information purposes and we do not assume that energy efficiency

programs translates one for one into overall improvements in energy efficiency.

CHAPTER TWO
TRENDS IN WASHINGTON ENERGY INTENSITY, DEMAND, AND ENVIRONMENTAL PRESSURES

Energy Intensity in the Industrial, Commercial and Residential Sectors

The following is a brief description of the past trends in energy intensity in Washington, comparable states, and for the U.S in general. For comparison, Oregon, Minnesota, and Colorado were selected, based on similarity of GSP and energy profiles. These trends illustrate Washington's energy setting, within which we have set-up our analysis, and from which we can interpret our results.

Industrial sector

The industrial sector is that subdivision of the economy that comprises manufacturing, agriculture, mining, construction, fishing and forestry. Its components can be identified by their Department of Commerce Standard Industrial Classification (SIC) codes corresponding to these economic activities. In addition, the DOE (U.S. Department of Energy) has used a number of indicators of energy intensity to characterize changes in the energy consumption pattern in the industrial sector. These include energy use per gross product originating, per value added, per value of production and per industrial production (DOE/EIA 1995). In our analysis, we use energy consumption per gross state product originating from the industrial sector. In this section, the energy intensities reported have not been controlled for price of energy, sectoral composition, or other factors, and thus may include combined effects of price, capital, labor, and other factors besides energy efficiency.

Figure 2.1 is a plot of energy intensity in the industrial sector in Washington, Colorado, Minnesota, and Oregon from 1977 to 1997. In Figure 2.1, we see that the energy intensity in Washington and Oregon is higher overall than that in their peer states. Yet, Washington and Oregon have generally seen greater declines in industrial energy intensity than the other states, especially since the early 1980s when the relatively greater

energy intensity coincided with a recession that decreased output value at that time
(OTED 2001).
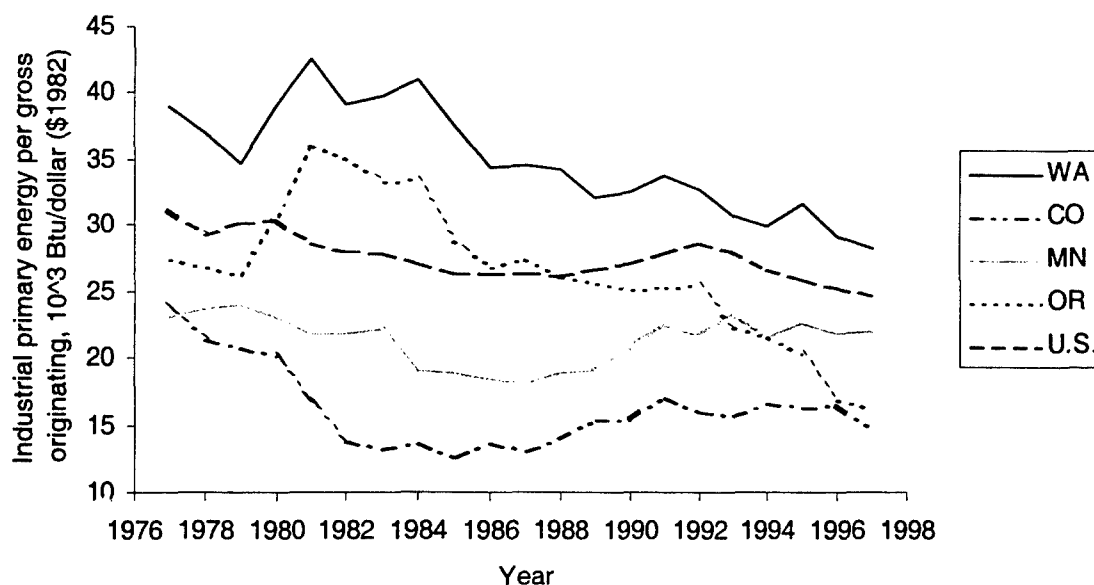
Figure 2.1. Industrial energy consumption per
gross state product originating in industry
(DOE/EIA 1999; BEA 1999).

Differences in energy intensity can be explained, in part, by the mixture of
industries that comprise the industrial sector. Certain industrial activities require a
significantly greater input of energy per dollar of output than others. Energy intensive
industries include mining (SIC 30000), stone, clay and glass (SIC 51320), primary metals
(SIC 51330), paper products (SIC 52260), chemicals (SIC 52280), and petroleum
products (SIC 52290). Figure 2.2 is a plot of the fraction of the gross industrial product
due to energy intensive industry from the four states of interest from 1977 to 1997. One
can see from the plot that the larger share of Washington's industrial product does not
originate from industry that is energy intensive, in comparison to Colorado, Minnesota
and the national average, and has generally declined since 1977.

Since the late 1980s, Washington saw a precipitous decline in the proportion of
energy intensive industrial activity, reportedly from declines in aluminum and pulp and
paper processing, and a shift towards high-tech industry during that period. In our

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analysis, shifts in the composition in the industrial sector comprise an important control factor.
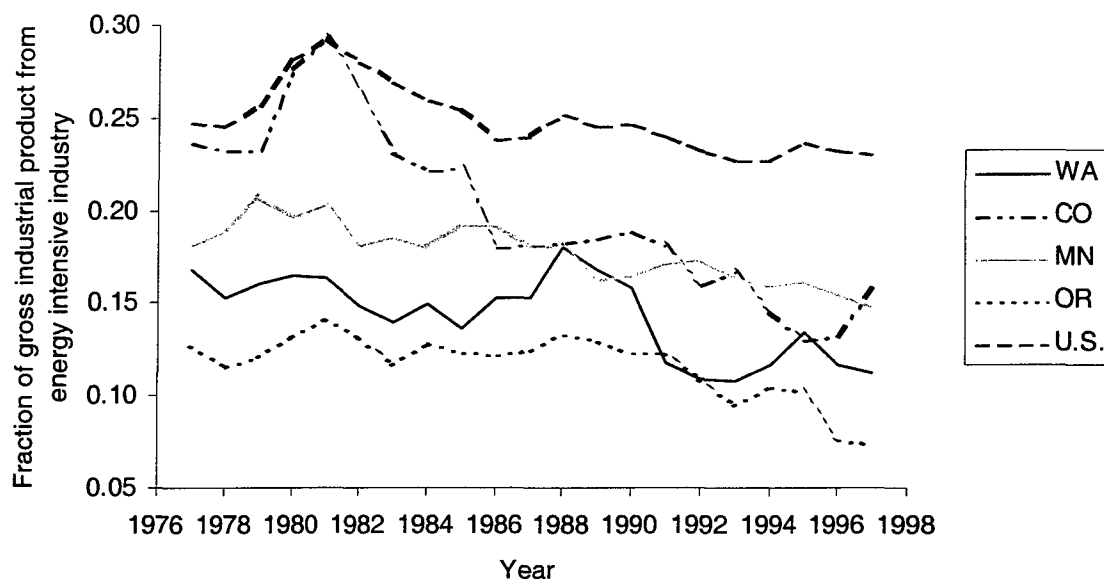
Figure 2.2. Fraction of gross industrial
product from energy intensive industry
(BEA 1999).

Recall that energy intensity is the ratio of a sector's consumption to its dollars of production; therefore, this ratio will, from year to year, increase if consumption increases at a faster rate than production. Likewise, if production increases at a faster rate than consumption, the energy intensity measure will decrease. Both energy consumption and industrial production are extremely volatile; energy consumption can vary by as much as 10 percent from one year to the next (OTED 2001). Yet, a comparison of Figures 2.1 and 2.2 shows that the large compositional fluctuations that occurred between 1984 and 1995 have had a relatively low impact on Washington's long term industrial energy intensity trend.

Figure 2.3 shows in more detail, the overall consumption and production of Washington State's industrial sector from 1977-1997. During the 1984-1997 period, the trend toward a lower industrial energy intensity was fueled by large increases in gross industrial product relative to industrial energy consumption as a whole. Consumption

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remained relatively stable throughout the period with the exception of a 6.2 percent annual average increase between 1985 and 1988 that coincided with an increase in the mix of energy intensive industries. At the same time, gross production increased at an annual average rate of 8.5 percent, and continued to increase through 1997. Clearly, while the aggregate trend in energy intensity since the mid-1980s may have been aided by the sectoral shift towards less intensive industry, it was also the result of more efficient industrial production—increased product with relatively stable consumption. Recall, too, that the period of 1990 to 1995 was a period of greater investment in conservation programs.
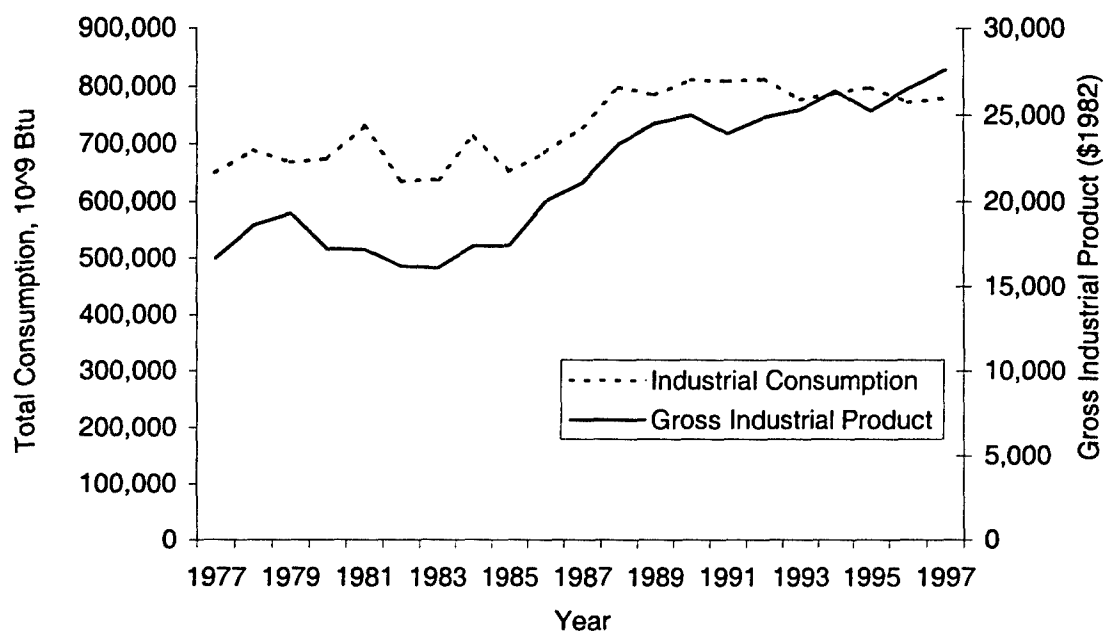
Figure 2.3. Total industrial consumption and gross industrial product, Washington State: 1977-1997 (DOE/EIA 1999; BEA 1999).

While these trends suggest that industrial DSM programs may have helped to increase production, this study does not specifically explore this linkage.

Commercial sector

The commercial sector is considered to be that economic sector that is "neither residential, manufacturing/industrial, nor agricultural" (DOE/EIA 1998b). As in the case of the industrial sector, there are a number of indicators of energy intensity that may be used to characterize the commercial sector's utilization of energy. Figure 2.4 is a plot of

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the energy consumption per gross state product in the commercial sector in Washington, Colorado, Minnesota, Oregon and the U.S. As in the industrial sector, commercial energy intensity in Washington has generally declined since the late 1980s.
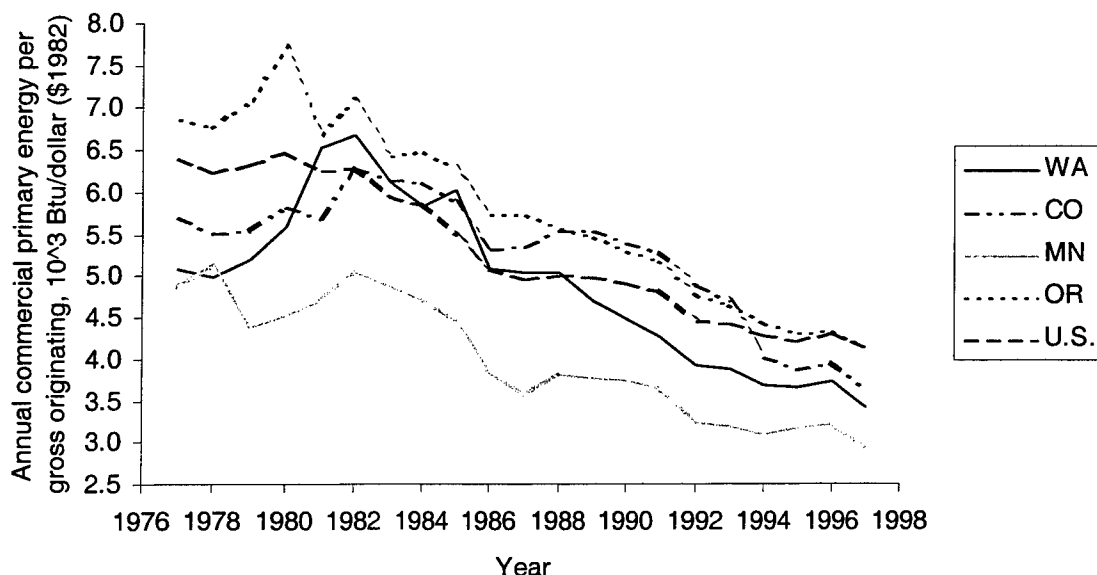
Figure 2.4. Commercial energy consumption per gross state product originating from 1977 to 1997 in Washington, Colorado, Minnesota, and Oregon (DOE/EIA; BEA 1999).

The commercial sector uses most of its energy for space conditioning and lighting of its buildings. According to the DOE/EIA (1998b), "commercial buildings include, but are not limited to, the following: stores, offices, schools, churches, gymnasiums, libraries, museums, hospitals, clinics, warehouses, and jails." The energy used for lighting and space conditioning is a function, in part, of the amount of floor space in the commercial sector. Therefore, an alternative measure of energy intensity in the commercial sector is energy use per square foot. Figure 2.5 illustrates the primary energy consumption per square foot in the four states of interest from 1977 to 1997. Inspection of Figure 2.5 reveals that after the early 1980s, commercial energy consumption per square foot in Washington has declined compared to that of Colorado, Minnesota and Oregon— although Washington still has generally exceeded its peers on this measure. The decline

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may be due to several factors, including the implementation of the state's building energy code; in 1977, the state's first energy code was voluntary, while in 1986 the statewide energy code became mandatory for all new buildings (DOE 2000.)
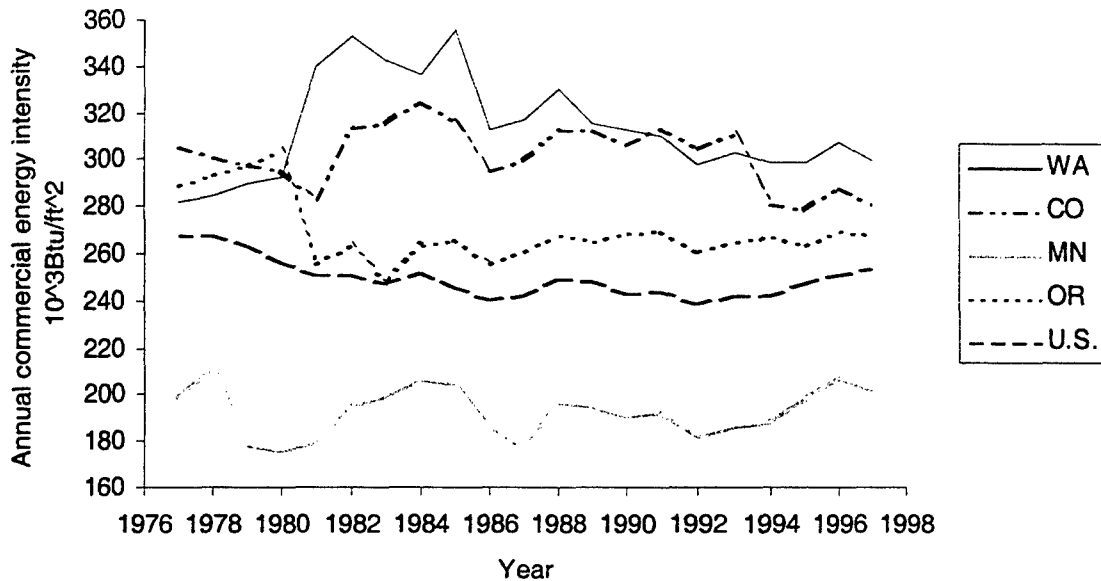
Figure 2.5. Primary commercial energy consumption per square foot of nonresidential floor space from 1977 to 1997 in Washington, Colorado, Minnesota, and Oregon (DOE/EIA; F.W. Dodge 1999).

Residential sector

Although we will not analyze the residential sector in a macroeconomic analysis of the benefits of energy efficiency, a review of general trends in household energy consumption in Washington is helpful in understanding the residential energy setting. Figure 2.6 shows the annual primary energy consumption per household while Figure 2.7 illustrates the annual primary energy consumption per capita from 1977 to 1997. Both indicate a general decline in energy intensity over the study period, likely due in part to compliance with energy codes. Through examinations of the expenditures on energy in the residential sector, we will connect these declines in energy intensity to benefits to several classes of residential energy customers.

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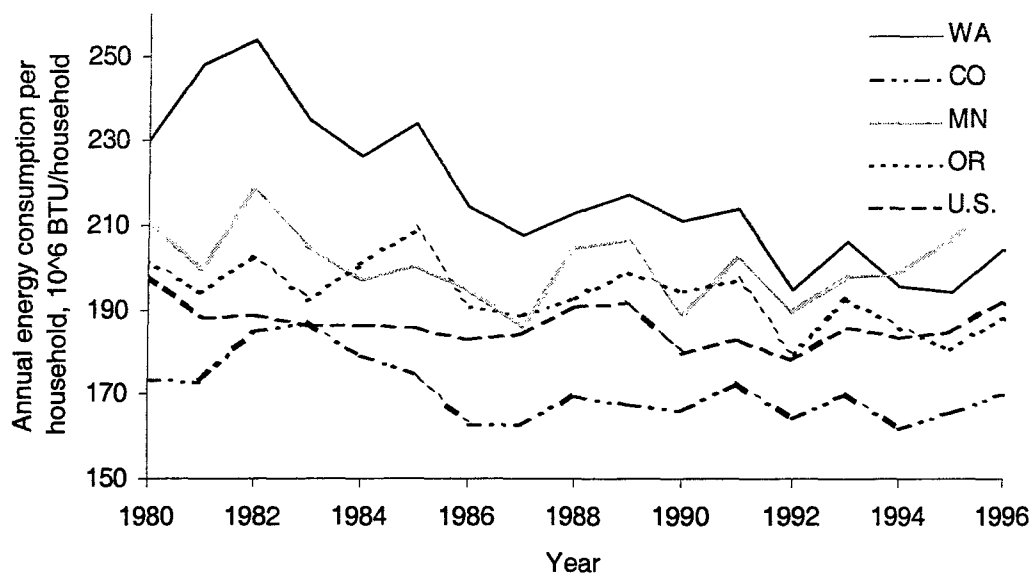
Figure 2.6. Annual per household energy consumption
for the United States and selected states
(Census 1999b; DOE/EIA 1999).
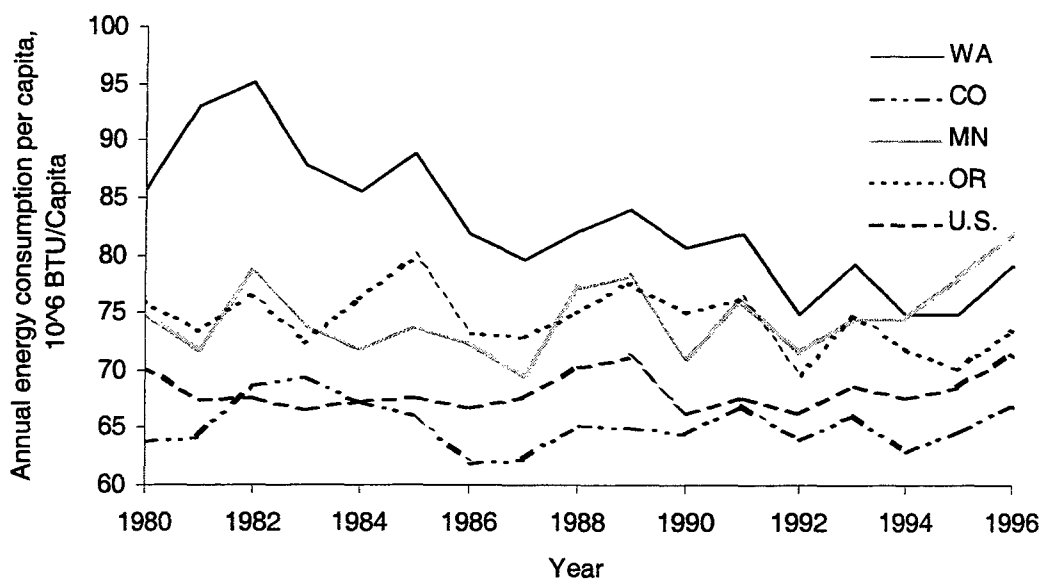
Figure 2.7. Annual residential per capita energy consumption
for the United States and selected states
(Census 1999a; DOE/EIA 1999).

Energy Consumption Drivers

In the last section we compared energy intensity in Washington with that of the U.S. and several of its peers. Here we present a discussion of drivers of energy intensity that serve as a basis of our projections for the future effects of energy efficiency programs in Washington.

Industrial sector

From the mid-1980s through 1997, Washington has seen the energy intensity of its industrial sector decline corresponding to a shift from more energy intensive industry (e.g., paper products, aluminum) to less energy intensive industry (e.g., information technologies). In addition, improved industrial processes have led to greater production relative to consumption. However, the on-going potential for energy shortages in the West has created an uncertain near-term future for energy intensive industries such as aluminum; cutbacks in power to the aluminum companies are currently in effect, and will likely continue for the next year or two to relieve demand pressure. Depending on these firms' ability to maintain production, these curtailments would naturally lead to a continued decline in industrial energy intensity. Recall too that past declines in the energy intensity of the industrial sector occurred during a period of investment in energy efficiency programs and increasing energy prices. Of these factors, continued high-energy prices in the long-term are not likely to occur, new capacity is under construction, long-term curtailment of energy-intensive industry may not be possible, and investment in energy efficiency programs are in decline. Considering this, industrial energy intensity may increase in the future.

Commercial sector

Energy intensity in the commercial sector may continue to follow the decline seen since the late 1980s and 1990s, as new commercial buildings are built to comply with the energy code. Yet, the increasing number of electric devices in the commercial sector may drive greater commercial energy intensity as well. Population forecasts suggest that growth in more temperate western Washington will continue to outpace that in the eastern part of the state (see Figure 2.8). Compared to the western part of the state, eastern Washington is typically warmer during the day, colder at night, more extreme in

the summer and winter, and requires a greater energy load for space conditioning. Thus, increasing space-conditioning loads in eastern Washington will likely support increased energy intensity in the commercial sector.
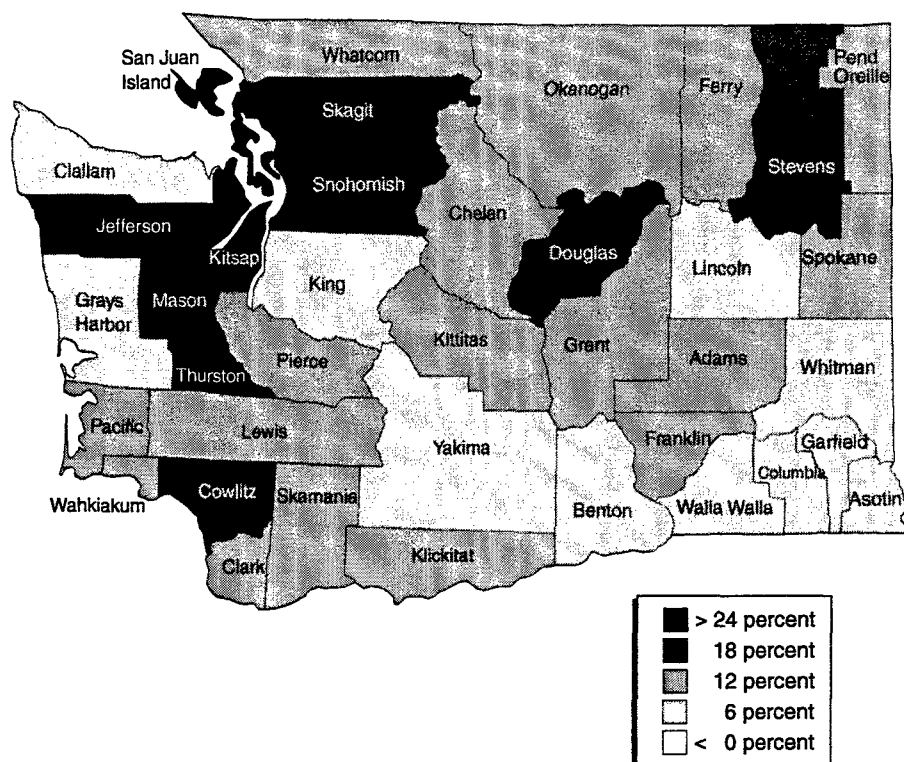
Figure 2.8. Forecasted population growth
by county from 2000 to 2010 (OFM 1995).

Residential sector

New homes in Washington must comply with the state residential building energy code. However, the code does not regulate many of the new electric devices and smaller appliances that may contribute to increased energy use. Population is expected to grow throughout the state, but is not likely to grow at the rate it experienced in the 1980s and 1990s (OFM 1995). Further, the areas of greatest growth will likely continue to be around areas of greatest existing infrastructure, in more temperate western Washington.

The population of eastern Washington is currently only approximately 20 percent of the state's total, but it is expected to increase in the next decade as well. As in the commercial sector, the more extreme climate in eastern Washington will continue to increase space-conditioning loads in buildings in eastern Washington, which will affect the residential buildings as well. A greater occurrence of low-income households in the eastern state also will continue to place greater energy costs on a population least able to bear this burden.

Energy Demand and Reliability

In all sectors, Washington's energy demand, particularly its electricity demand, is rising. Yet Washington's once ample source of inexpensive hydroelectric power continues to play a diminishing role in satisfying this demand. In fact, economic development throughout the West contributes to competing demand for limited energy resources and to increasing regional energy reliability problems.

As a member of the Western Systems Coordinating Council (WSCC), Washington shares an electricity transmission network with California, Oregon, Idaho, Montana, Wyoming, Nevada, Arizona, Utah, Colorado and New Mexico. The WSCC also includes parts of Canada (British Columbia and Alberta) and Mexico (Baja California). In part because of its size and climatic diversity, peak loads in Washington are coincident with peak loads in the various regions of the WSCC. The economic growth in these states may limit the ability of Washington to import electricity to meet regional coincident demand. Compounding the effects of the drought conditions in the Pacific Northwest, the dysfunctional electricity markets in California, the North American Electric Reliability Council concluded that the Arizona-New Mexico-Southern Nevada and the California-Mexico areas of the WSCC may not be able to accommodate a widespread severe heat wave or a significantly higher-than-normal forced outage rate for generation; these areas are experiencing a continuing trend of peak demand growth that exceeds the addition of new generation facilities (NERC 1999).

Through 2010, peak demand and annual energy requirements for the Northwest Power Pool (NWPP) within the WSCC are projected to grow at annual compound rates of 2.1 percent and 1.8 percent, respectively. Resource capacity margins for this winter-

peaking area range from between 11.5 percent and 19.4 percent of firm peak demand (WSCC 2000). The reserve margin is a measure of the ability of the transmission system to handle unexpected increases in load, and includes those customers whose service the utilities may curtail under peak load conditions. If these interruptible consumers receive service, the reserve margin drops. Restructuring in the electricity industry places a premium on the efficient use of resources, and reserve margins can be expected to decline as restructuring continues throughout the region.

By 2004 the reserve margin, less generation additions, is expected to drop near the minimum margin line. According to the WSCC (2000), an average of 3,000 MW of the planned 30,214 MW additions must enter service each year for the next decade to meet demand. Energy efficiency in Washington also has the potential to lessen the impacts of regional peak demands on Washington consumers. Over the period 1979-1995, BPA's investments alone in conservation have displaced the demand for output of two 400 MW generators.

Environmental Pressure

In the same way that the growth in Washington has increased energy demand in the state, it has also increased environmental pressure. In addition, drought conditions have affected hydroelectric output of the region, while biological requirements to protect certain species such as salmon further limit the ability of the state to provide hydroelectric power.

While state air quality issues do not reach the level of concern they do in certain air basins of other states (e.g. California and Colorado), air quality has decreased, particularly near growing population centers. Further population growth in these areas will exacerbate problems in air quality due to energy use. As in other states, the primary contributor to decreased air quality throughout Washington is motor vehicles, but emissions from electricity production and industry also contribute. The Centralia coal-fired plant in Lewis County, located approximately 85 miles south of Seattle, has been the target of concern for emissions contributing to acid rain in Mount Rainier National Park. Coal and gas-fired pulp and paper mills and aluminum smelters are located throughout southern Washington, Puget Sound and in parts of eastern Washington.

Based on data from the Environmental Protection Agency (EPA), Figure 2.9 illustrates areas of non-attainment status, for criteria pollutants regulated under the Clean Air Act (EPA 2001). As such, parts of King, Pierce, Yakima, Spokane and Walla Walla counties are in non-attainment for particulate matter less than 10 microns in size (PM10); parts of Yakima and Spokane are also in non-attainment for carbon monoxide (CO). It is important to note that the air quality is time dependent and periods of poor air quality are the result of both natural and anthropogenic causes. Yet, inspection of Figure 2.8 and Figure 2.9 reveals that continued growth is expected in counties where air quality is already a concern—in both western and eastern parts of the state.
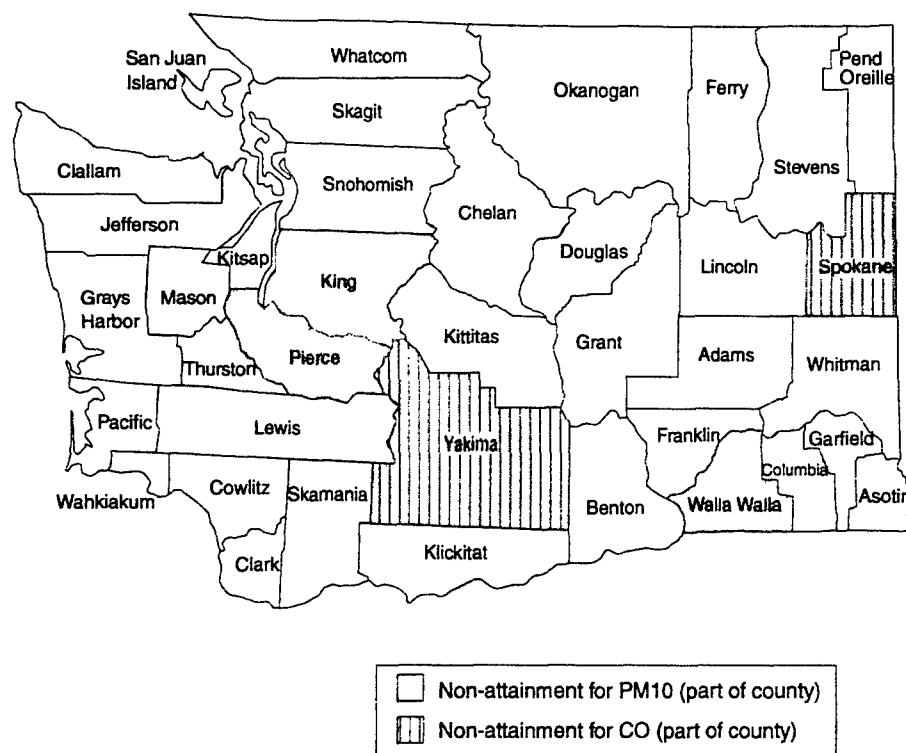
Figure 2.9. Non-attainment areas for CO
and PM10 by county in 2001 (EPA 2001).

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Conclusions

Washington's energy use has increased in the past, and will continue to increase in the future. Energy planners in Washington must continue to consider options for meeting this growing demand, beyond that which has been provided by the state's existing hydroelectric and thermal generation system. Yet even with increased consumption, energy intensity has generally decreased in all sectors over the past 20 years. In the following chapters, we show that the declines in energy intensity in the industrial and commercial sectors have had cost-effective positive benefits for Washington's economy, its environmental quality, and its citizens. While the interplay of prices, government regulations, efficiency programs, climate, and economic factors that contributed to historic declines in energy intensity may not be present in the future, we argue that the potential benefits of energy efficiency may continue if properly encouraged.

CHAPTER THREE

ENERGY EFFICIENCY IN THE INDUSTRIAL AND COMMERCIAL SECTORS, ECONOMIC GROWTH, AND ENVIRONMENTAL BENEFITS

This chapter presents our analysis of the benefit of energy efficiency in the industrial and commercial sectors on the economic output of the state, or gross state product (GSP), from 1977 to 1997. In addition, we compare this benefit to the investments and savings of selected utility energy efficiency programs over this period. We also speculate as to potential future benefits of energy efficiency in the commercial and industrial sectors. Finally, we examine some of the environmental benefits of energy efficiency.

Energy Efficiency and the Washington Economy: 1977-1997

The econometric analysis determines the average effect of energy intensity and other factors on GSP in the 48 contiguous states. To determine the benefits for Washington, we use the national averages on data from 1977 to 1997 as a baseline for determining the effects of changes in Washington's energy intensity, while controlling for energy price, sectoral composition and other factors, on Washington's per capita economic growth.

The analysis shows that changes in energy intensity are associated with the growth of GSP. As illustrated by Table A.5, from 1977 to 1997, GSP per capita in Washington grew from $20,198 to $31,183. According to the analysis, if energy intensity had remained at the 1977 level over this period, then GSP per capita would have been 2.7 percent less than its actual 1997 value. Figure 3.1 shows the actual evolution of GSP per capita and the predicted evolution in the case of constant energy intensity.
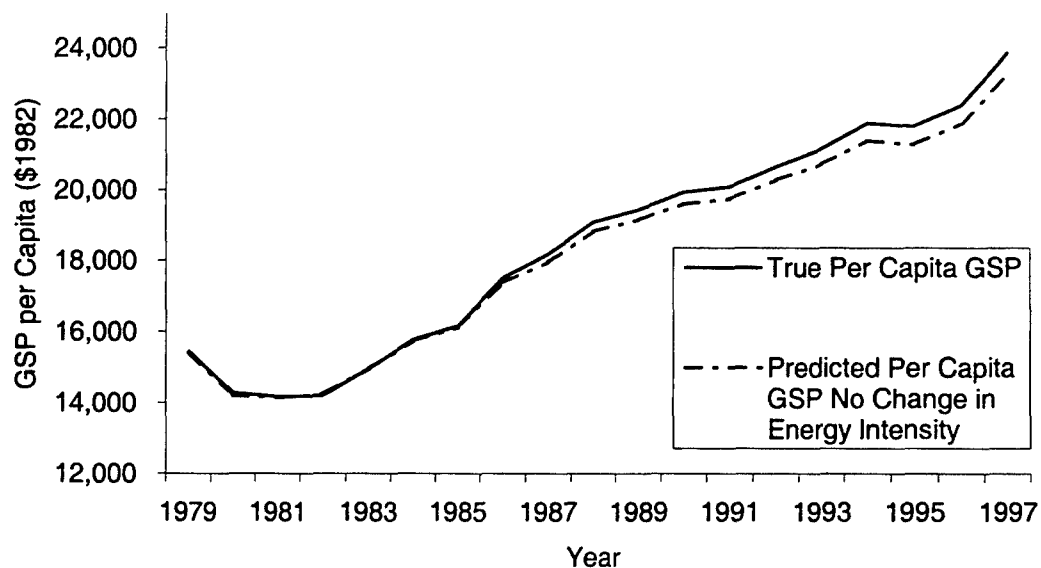
Figure 3.1. Actual GSP per capita from
1979 to 1997 and GSP per capita in the case
of constant energy intensity.

As shown in Table 3.1 this economic growth is equivalent to $819 per capita in

1997. When we examine the impact of energy intensity across states with industrial

characteristics similar to Washington, we find that the impact on GSP per capita is

potentially larger than the national average. In this case, the increase in GSP per capita

due to reductions in energy intensity that has been controlled for various exogenous

factors is $1,120 per capita.

Table 3.1. The benefit of energy intensity
improvements to the Washington economy.

Effect of energy intensity on the WA economy	Increase in 1997 GSP per capita	Increase in total 1997 GSP (billions)
National average effect	$819	$4.6
States similar to Washington effect	$1,120	$6.3

The Value of Energy Efficiency Programs to Washington

Throughout the study period, there have been state- and utility-sponsored energy efficiency programs. Often, these programs target specific end-users and end-uses such as lighting, home insulation, and facility retrofitting. The purpose of the programs is to promote cost-effective energy efficiency improvements in Washington's industries, stores, offices, farms, and homes. In order to draw solid conclusions about the impact of energy efficiency programs on GSP we need to include national efficiency program expenditure data in our model as an explanatory variable. Absent this information, we take an indirect approach. In this section we compare increases in GSP to estimates of energy and monetary savings reported for state-sponsored energy efficiency programs to the state of Washington. We recognize that the extent to which the programs have actually contributed to declines in energy intensity is unknown.

The previous section showed that since 1977, reductions in energy intensity have been associated with economic gains of $819 per capita, or approximately $4.6 billion in 1997. In fact, the cumulative gains over the entire period amount to approximately $31.4 billion. Likewise, we can estimate the amount of energy that would have been consumed had energy intensity remained constant over the time period, and describe this savings in terms of dollars per unit of energy saved ($/GWh). This number serves as a rough benchmark for comparison to DSM program costs. Note that these are savings only due to energy intensity improvements in the commercial and industrial sectors, and it is assumed that the energy saved is the result of changes in energy intensity independent of the control factors. From modeled benefits to GSP over the study period, in terms of $/GWh, and utility investment and savings rates, also in terms of $/GWh, we can make an informative comparison of benefits to costs. Note however, that we cannot make conclusions about the effectiveness of utility conservation programs, as we have not shown a specific link between investment in energy efficiency programs and effects on energy intensity.

Unfortunately, the data that describes the expenditures and energy savings of state-sponsored DSM programs is limited. Wide-scale utility reporting generally did not

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occur prior to 1989. While historic investment data from most of the state's major utilities are available from the Washington Office of Trade and Economic Development for the period 1990-1999 (OTED 2000), matching estimates of energy savings are not available for this entire period, nor are estimates attributed only to commercial and industrial sectors easily derived from them. Further, the energy savings estimated by the utilities do not account for the control factors and may also be due to changes in labor and capital. The Bonneville Power Administration (BPA), which supplies almost 50 percent of the electricity in Washington and accounts for a substantial portion of utility investment in energy efficiency, does provide detailed data from 1982 to 1998. Therefore, we use BPA's reported investment and savings in commercial and industrial sector programs, although RAND has not independently verified these estimates. Note, too, that BPA markets power to various utilities and end-users, not all of whom are in Washington.

For our analysis, we must also assume a value for program life, as investment must correspond to energy savings over the life of the program. Of the conservation programs considered in the Washington State Electricity System Study (OTED 1998), 122 programs have endured, on average, for at least seven years. However, 50 of these programs are currently on-going, 23 for more than 10 years, and three for more than 20 years.

Our analysis suggests that BPA's cumulative investment from 1982 to 1997, adjusted for inflation, in commercial and industrial sector conservation programs was approximately $475 million. BPA's cumulative investment in conservation in all sectors was $1.94 billion. Note that BPA's investments cover the northwest region, not only Washington State. Further, the BPA reports "end use energy" saved as a result of these programs in units that do not take into account energy saved by avoiding transmission losses or generation. Assuming a program life of 10 years, we estimate that 21,164 GWh of electricity were saved in commercial and industrial sectors alone, which is equivalent to a total energy savings of 43,785 GWh.[6]

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[6] Total energy savings were calculated using system loss conversion factors provided by the EIA. These figures may not be entirely accurate for Washington, which serves much of its electricity load through the state's hydroelectric system. Note that these factors describe more than only transmission loss.

We find that the average cost of BPA programs begun between 1982 and 1997 was approximately $11,000/GWh (1.1 cents/kWh), while the estimated benefit to Washington of all changes in energy intensity over the time period (1982-2007) is $30,912/GWh (3.1 cents/kWh)[7]. If BPA's estimates of investment and savings are indicative of utility investment and savings as a whole in Washington and the fact that the programs have indeed affected energy intensity, then such a comparison favors these programs. To determine the relationship between energy efficiency programs and changes in energy intensity, and to identify an actual return on investment, would require additional analysis. It is important to note that the notion of a return on investment in this context applies to the state economy as a whole and not to those who participated in energy efficiency programs in particular.

We do not know the true benefits of DSM programs with certainty, nor do we know the effect of such programs on energy intensity. However, we may ask how accurate the programs' reported costs needed to be in order for the programs to be cost effective as compared to our benchmark. This analysis suggests that had BPA programs saved only 35 percent of the energy reported, the unit cost of energy ($/GWh) of such programs would have been roughly equivalent to our predicted savings to the state. Thus, the programs were cost-effective, even if their energy savings were overestimated by a factor of three, or if program costs were three times more.

Future Benefits of Energy Efficiency to Washington

In the previous section, we have shown that improvements in energy intensity, perhaps influenced by energy efficiency programs, have resulted in economic benefits to the state. In what follows, we project our results into the future (2015) and determine the future value of energy efficiency when making some assumptions regarding future changes in energy intensity.

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[7] These savings were calculated for the period 1982-2007, under the assumption of a 10-year program life. All projections beyond 1997 assume average growth rates of the 1977-1997 period for per capita GSP, population, and changes in energy intensity measures. We compare the average benefit of changes in energy intensity to the entire economy with the costs of particular programs, which presumably affect a small, but significant, amount of the aggregate changes in energy intensity. It is difficult to quantify a discount rate for the benefit streams relative to the costs. Assuming a 5 percent discount rate, the reported benefits exceed the costs by a factor of approximately 1.24.

In the past, improvements in energy efficiency often coincide with improvements in industry practices and investment in new equipment and processes. Yet, with the rapid advance of technology and changes in energy services, it is possible that the gains in energy intensity in Washington may be reversed. Therefore, we consider a set of future scenarios based upon possible changes in energy intensity in the commercial and industrial sectors. These projections cannot be tied directly to the funds that may be spent on future efficiency measures, but they do allow us to speculate regarding the continued benefits of energy efficiency to the Washington economy.

Inspection of Figures 2.1 and Figure 2.4 reveals three general trends in energy intensity in Washington. From 1977 to 1997, energy intensity in both the industrial and commercial sectors declined. However, the average over this period hides two phases of energy intensity changes. From 1977 to 1985, energy intensity in Washington increased, but from 1986 to 1997, the average energy intensity decreased. These changes are due in part to shifts in the industrial mix—from energy intensive resource and manufacturing industries (e.g., pulp and paper, aluminum processing) to less energy intensive high-tech commercial activities (e.g., software development and biotech). Gains in energy efficiency have also contributed. Figure 3.2 presents the three scenarios as extrapolations of trends in energy intensity changes for the industrial and commercial sectors.
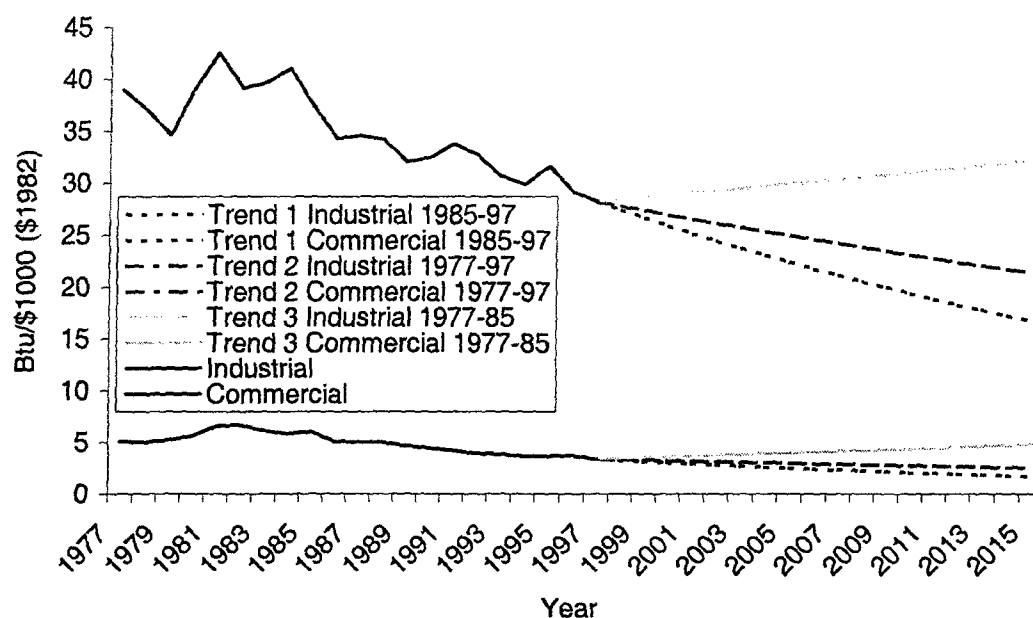
Figure 3.2. Trend of primary energy
intensity in Washington in the industrial and
commercial sectors.

In one scenario, energy intensity increases as it did from 1977 to 1985. In the
second scenario, energy intensity declines moderately according to the 1977 to 1997
average change. In the third scenario, energy intensity declines as from 1985 to 1997.
Using the national average coefficients calculated previously , we estimate expected
economic growth for the three scenarios. In addition, we calculate low and high
estimates for the effect of energy intensity on the state economy based on the standard
error of our analysis. Recall that these coefficients derive from our analysis that controls
for price, sectoral composition, and other factors. We compare these nine estimates
against a baseline that assumes no change in energy intensity from 1997. Table 3.2
presents the nine estimates of the changes in GSP per capita based on scenarios of the
commercial and industrial sectors combined.

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Table 3.2. Estimates of future economic
benefits of reductions in energy intensity to
Washington in terms of per capita GSP .

Estimate of the effect of energy intensity on the Washington economy	1997 Benefits	2015 Changes in GSP per capita from 1997		
		1985-1997 trend Large decrease in energy intensity	1977-1997 trend Moderate decrease in energy intensity	1977-1985 trend Increase in energy intensity
National Average – Higher Impact	$1,059	$1,895	$910	-$737
National Average – Mid-Impact	$819	$1104	$537	-$420
National Average – Lower Impact	$579	$325	$169	-$101

Our analysis shows that if energy intensity in the commercial and the industrial sectors increases as it did prior to 1985, the cumulative net loss in GSP per capita by 2015 could be about $420 per capita as compared to the baseline. On the other hand, the analysis shows that reductions of energy intensity can continue to have large-scale economic benefits to the state. If energy intensity in Washington continues to decline at its average rate from 1977 to 1997, we could expect an additional increase in GSP per capita of anywhere between $169 and $910 per capita by 2015, depending on the estimated benefits of decreased energy intensity. Better still, if energy intensity in Washington declines according to the recent 1985-1997 trend, we could expect an additional increase in GSP per capita of anywhere between $325 and $1,895 per capita, depending on the estimated benefits of decreased energy intensity. Note that these measures of energy intensity include controls of our analysis.

If one believes that there is a chance that energy intensity could worsen in the absence of government policy (e.g., energy efficiency programs), and that the energy intensity may increase similar to that of the 1977 to 1985 period, but that energy efficiency programs can achieve improvements similar to those made from 1977 to 1997, the potential benefit could be $957 per capita (the difference of the average values in column 4 and column 5 of Table 3.2.) In a state of 5.6 million residents (U.S. Census 2000), the potential gain in GSP in 2015 could range from $1.5 billion (using the low

values under these same assumptions) to $9.2 billion (using the high values under these assumptions).

Environmental Benefits of Reduced Energy Intensity

Of the various environmental conditions associated with energy consumption, the most direct connection is between energy consumption and air emissions. These include various air pollutants regulated under the Clean Air Act (e.g., particulate matter, SO_2, NO_X, CO) and CO_2. In Washington, there is concern about the operation of the system of hydroelectric dams and their impact on various species protected under the Endangered Species Act. These impacts are more difficult to quantify and link to changes in energy intensity. Furthermore, it is unlikely that reduced energy intensity would affect hydroelectric generation as much as it would the marginal thermal generation plant powered by non-renewable sources. Hydropower is the power produced at the lowest operating cost and is produced regardless of whether or not demand is such that all the power is used. Fossil-fueled plants, on the other hand, are ramped up and down as power needs change. Since changes in energy intensity are due to the fossil-fueled plants, then, in this analysis we focus only on the air quality effects from the fossil-fueled plants.

We calculate emissions reductions due to reduced energy intensity in the industrial and commercial sectors, after considering control factors, from the total electricity used in each sector, in comparison to the electricity consumption if energy intensity had not changed since 1977. We also consider the fact that Washington State receives its power from a variety of sources in the Western Systems Coordinating Council region; thus, emissions rates and the state's total emissions from electricity consumption are calculated from the aggregate emissions in that region. Finally, we use the aggregate emissions from fossil-fueled generators in that region since those would be on the margin the emitters reduced or increased in any one year.

If we consider an aggregate emissions level from fossil fueled power production in the WSCC, reduced energy intensity in the commercial and industrial sectors displaced approximately 20,000 tons each of SO_2 and NO_x. In addition, carbon dioxide emissions were reduced from approximately 61 million tons to approximately 51 million tons in 1997 by reduced energy intensity in Washington's commercial and industrial sectors.

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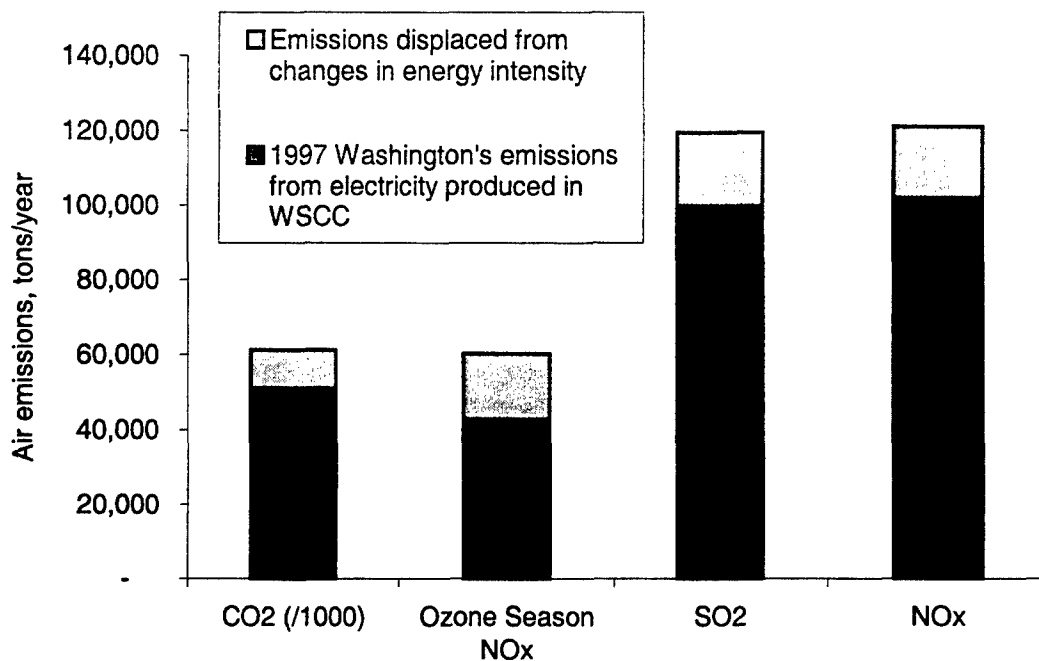
Figure 3.3. Emission reductions from electricity produced
in the WSCC due to changes in energy efficiency in
Washington (EPA 2000).

Air quality has decreased in Washington, particularly near growing population
centers. Further population growth will exacerbate problems in air quality due to energy
use. While the primary contributors to decreased air quality throughout Washington are
motor vehicles, emissions from electricity production and industry also contribute. Our
analysis shows that, in addition to the economic benefits, reductions in energy intensity
have slowed the increase in air emissions throughout the Western region, including
Washington State.

CHAPTER FOUR
BENEFITS OF ENERGY EFFICIENCY IN THE RESIDENTIAL SECTOR

While changes in GSP due to our controlled changes in energy intensity may indicate the benefit of commercial and industrial energy efficiency to the state, no convenient macroeconomic indicator is available that can quantify benefits of energy efficiency in the residential sector. Therefore, the following discussion presents a number of benefits that have come to Washington households due to reductions in household energy intensity, including financial savings, increased comfort and an increased number of energy services. Our comparison of household energy consumption and expenditures in Washington with those of other states and across income levels, suggests that reductions in household energy intensity have benefited the state's citizens, particularly those of low-income households in less temperate parts of the state.

Residential Energy Consumption Characteristics

As in the industrial and commercial sectors, changes in residential energy consumption are due to a number of factors that include: climate, size of household, age of the home and its appliances, the presence and enforcement procedures of a residential energy code, and the price of energy. Previously, we presented two indicators of energy efficiency for the aggregate residential sectors in Washington, Colorado, Minnesota, Oregon, and the U.S. in general; i.e., residential energy consumption per household (Figure 2.6) and residential energy consumption per capita (Figure 2.7).

Table 4.1 lists the percent changes in per capita primary energy consumption in Washington, Colorado, Minnesota, and Oregon according to Ortiz and Bernstein (1999). Also included is the year in which the state adopted a residential energy efficiency building code. Accordingly, primary residential energy consumption per capita in Washington has fallen by more than five percent since the 1970s[8]. Similarly, in Minnesota and Oregon, primary energy consumption per capita has decreased by more

than three percent and six percent, respectively. In Colorado, a state with no residential building energy code, primary energy consumption per capita has not changed. Thirty-five states in the U.S. have residential energy codes, and the average change in annual per capita energy consumption for the 48 contiguous states over the same time interval has been a 1.7 percent increase.

Table 4.1. Changes in residential primary energy consumption per capita excluding transportation (Ortiz and Bernstein 1999).

State	Year of residential energy code implementation	Percent change in per capita energy consumption from 1970-1978 average to 1988-1995 average
WA	1986	-5.4
CO	NO CODE	0.0
MN	1976	-3.3
OR	1975	-6.2

In Washington, the changes in per capita energy consumption have reduced real per capita energy expenditures in the state, particularly since the 1980s. The history of real residential energy expenses appears in Figure 4.1. The 1997 residential energy expenses per capita in Washington were $380[9] (DOE/EIA 1998a). The 1997 expenses represent a 25 percent decline in real energy expenses from the high of $512 (1998$) in 1983. The $132 annual per capita savings per year from 1983 to 1997 translates into a gross savings to Washington residents of $740 million. This comprises a combination of both improvements in energy efficiency as well as energy prices, which have generally decreased in real terms during the study period.

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[8] Primary energy consumption describes consumption of energy with respect to its source, as opposed to consumption at its end use. Primary energy, thus, exceeds end use energy in that it also accounts for system and transmission losses.
[9] For comparison, the consumer energy savings in Chapter Four have been adjusted according to the Consumer Price Index, and reported in 1998$.
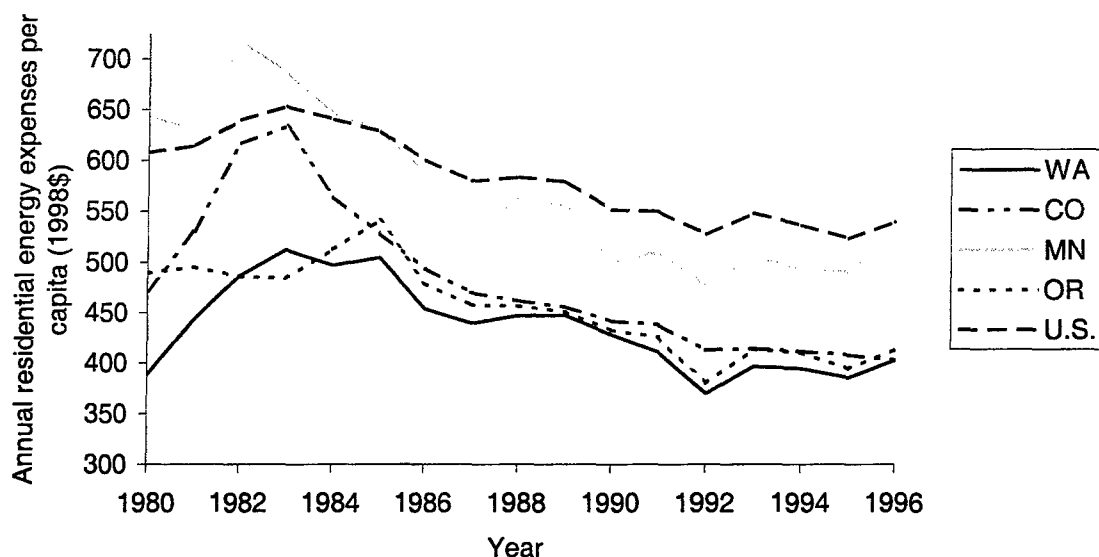
Figure 4.1. Real energy expenses per capita in the residential sector in Washington from 1977 to 1997 (DOE/EIA 1998b).

Energy Efficiency and Low-income Households

Energy needs differ among households and their annual expenses for energy vary between approximately $1,000 and $2,000. Higher-income households tend to use more energy than lower-income households; however, the percentage of household income devoted to energy services is greater for low-income households. According to the 1997 Residential Energy Consumption Survey (RECS), the national average energy expenditures in 1997 for a household in the $5,000 to $9,999 income bracket were $985 ($1,000 in 1998$). However, for a household in the $75,000 and above income bracket, the expenditures were $1,864 (1998$); see Figure 4.2. Thus, average energy expenditures in the highest income group are almost twice that of the lowest income group and their income is more than seven and a half times greater.
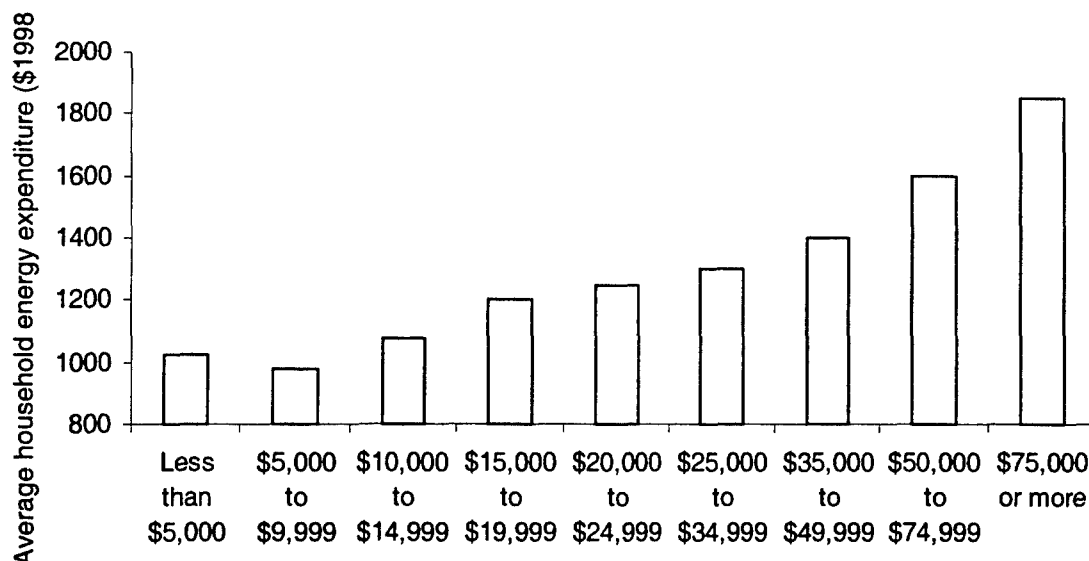
Figure 4.2. Nationwide average energy expenditures per household
by income level (DOE/EIA 1999).

Furthermore, the realization of any savings in the residential sector is a function
of the pattern of energy utilization in the household. When we compare expenditures by
end-use, we find that as much as two thirds of energy-related expenditures are for the
principal end uses of space conditioning, water heating and refrigeration (see Figure 4.3).
Consider these end-uses to be essential energy services since they are shared across all
income classes. The nationwide average expenditures per household for these services
was $725 in 1997 for households with incomes less than $10,000, and $876 for
households with incomes between $25,000 and $49,999—a 20 percent increase for a
three-to-five-times greater household income. Savings, therefore, in essential energy
services will be with respect to total household energy expenses more beneficial to the
lower-income household than to other households, and the comfort and utility derived
from essential energy services will be more sensitive to energy price and equipment
efficiency in lower-income households than in higher-income households. As a result,
energy savings may also have greater effect on disposable income of lower-income
households. For a more complete survey of low-income household expenditures on
energy, refer to Bernstein et al (2000). In general, we conclude that while residential
energy efficiency improvements provide benefits to all households, lower-income

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households are especially sensitive to energy costs, and so the benefits may be more significant.
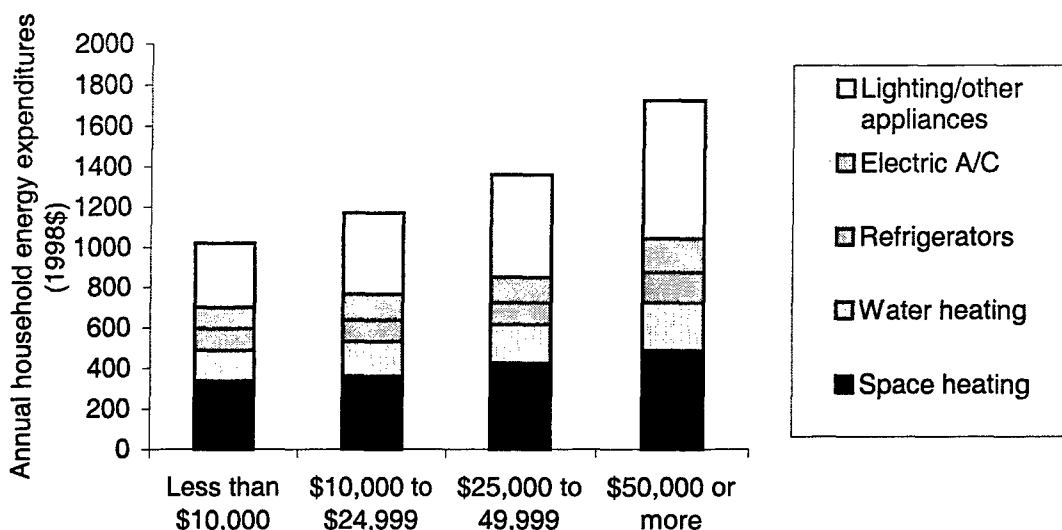
Figure 4.3. Annual energy expenditures by end use and household income (DOE/EIA 1999).

The disproportionate energy burden already borne by these households is exacerbated by their relatively inefficient use of energy; the housing occupied by low-income households tends to be older than the average, and therefore designed and built in a less energy efficient manner and equipped with less energy efficient fixtures and appliances. A study of low-income households found that 64 percent of households with less than $5,000 annual income have ceiling insulation, compared with 91 percent of households with more than $50,000 annual income, and that 14 percent of the former group versus five percent of the latter group have a more than 20-year old refrigerator (Chandrasekar et. al 1994). Among residences heated primarily with natural gas, those built since 1980 use 43 percent less energy than those built between 1940 and 1979 (DOE/EIA 1995).

Circumstances in Washington differ somewhat from the national picture, however. Washington tends to enjoy lower energy prices than the national average. Furthermore, only 11.9 percent of families earned below $16,400 (thus living below the federal poverty level, FPL) statewide in 1997 (OFM 1999). Overall, the percent of

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families in Washington living below the FPL is below the national average; in fact, Washington ranked 37th based on a three-year average from 1996-1998 Census (2000). Furthermore, Washington falls in a relatively moderate climate zone, and population growth in Washington is not expected to grow at nearly the same rate as it did in the 1980s and 1990s (OFM 2001). Population is more likely to expand in greater proportion around existing infrastructure and economic bases, i.e. in the more temperate western part of the state.

However, much of the low-income population lives in the eastern part of the state, and experiences greater heating and cooling needs than those in western Washington. As shown in Figure 4.4, more than 20 percent of families in the most of eastern Washington live below the FPL (OFM 1999), well above the national average.
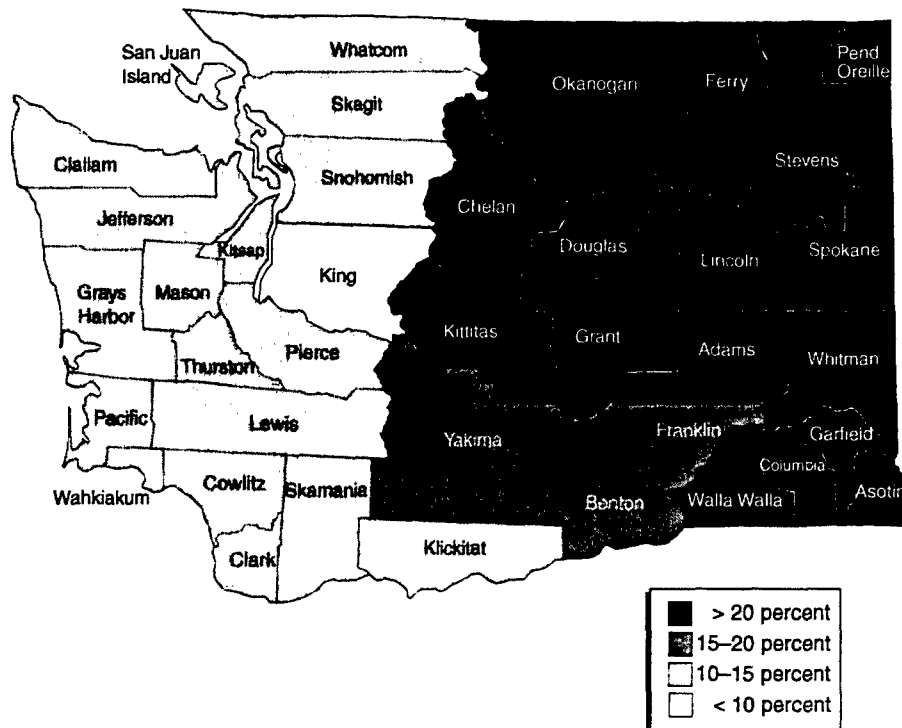
Figure 4.4. Percent of Washington families living in poverty (OFM 1999).

In general, Washington's rural households in the eastern part of the state tend to live in an area of more extreme climates and have limited natural gas service, so must rely on more expensive propane gas and less efficient electric heating. Furthermore, they must use electricity for services such as water pumping and outdoor lighting that are provided by municipalities in urban areas. Thus, relative energy burdens on low-income households in Washington remain large: Low-income households (below 150 percent of FPL) spend more than ten percent of their income on energy, whereas median-income households spend less than three percent of their income on energy (NCLC 1995). In Washington, the typical low-income household (below 100 percent of FPL) spends $754 per year on energy, compared with an average for median-income households of $995. These expenditures are not uniform throughout the state, nor throughout the year; for example, the average electricity bill for low-income households during the summer of 1992 was $242 in Yakima, but only $170 in Bellevue (Colton 1994).

Based upon estimates of energy expenditures by income level (EIA 1997) and estimates of savings associated with energy efficiency improvements such as weatherization [10], Figure 4.5 shows the energy burden on Washington households by income level, and the potential reduction of energy expenditures with energy efficiency improvements. Note that the gap widens for lower income households accounting for the fact that lower-income homes are generally older and of poorer construction. Figure 4.6 shows the energy burden on Washington households by income level, and the potential reduction of this burden due to improvements in energy efficiency.

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[10] Weatherization includes weather stripping, caulking, installation of storm windows and doors, insulating attics, and retrofitting space and water heaters (Berry, Brown and Kinney 1997).
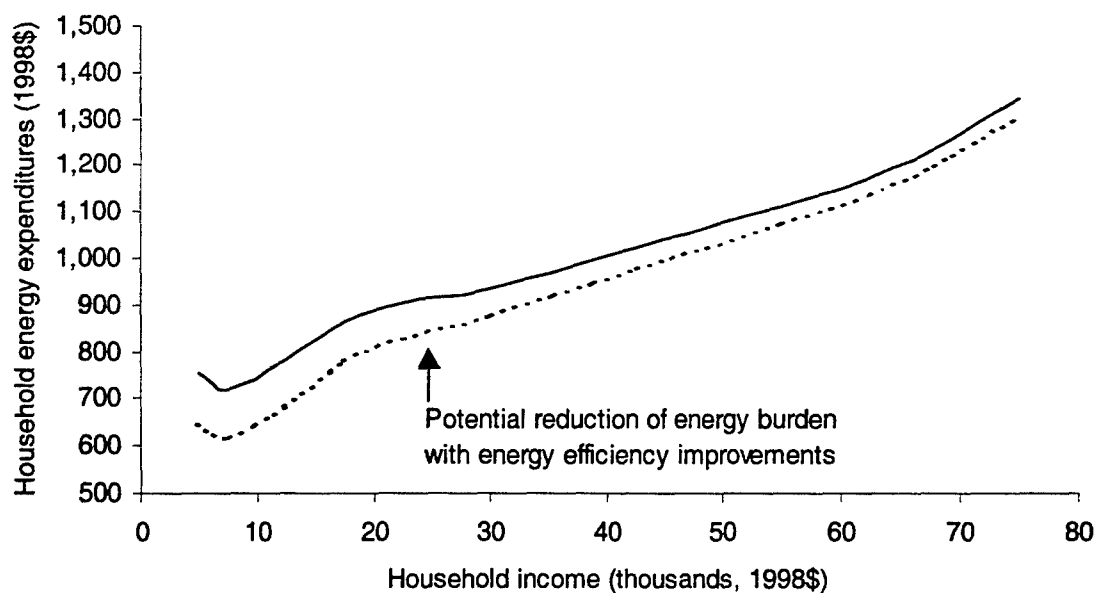
Figure 4.5. Washington household energy
expenditure (EIA 1997; Berry, Brown and
Kinney 1997).
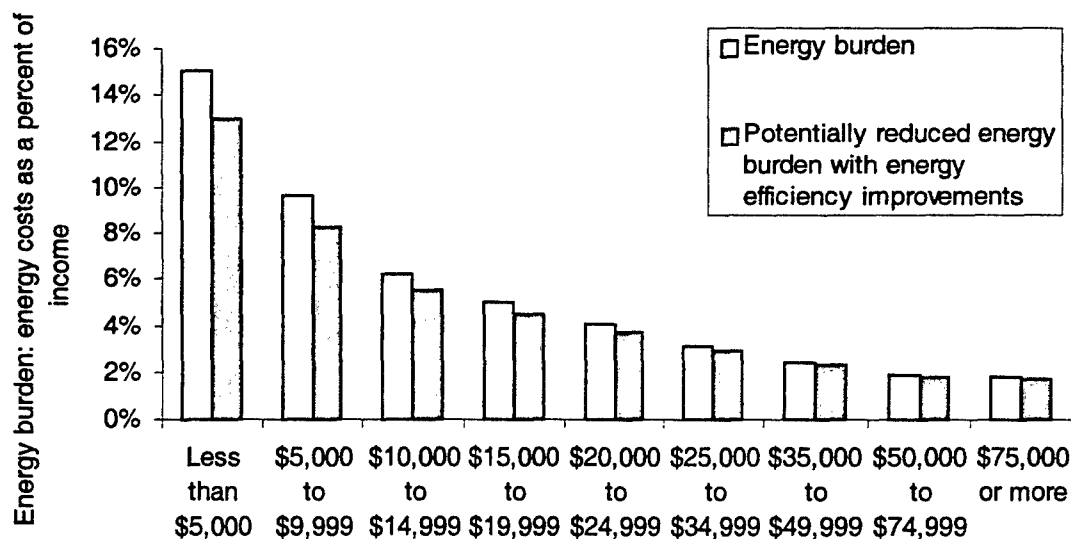
Figure 4.6. Washington household energy expenditure as a percentage of income and
potential reduction of energy burden with energy efficiency improvements
(EIA 1997; Berry, Brown and Kinney 1997).

In recognition of these energy burdens, numerous federal, state, and utility administered programs have sought to reduce energy costs, by direct financial assistance and through energy efficiency programs. The federal Weatherization Assistance Program (WAP) was established in 1974 under the Community Services Act, to reduce the cost of heating and cooling by improving building energy efficiency.

A 1997 metaevaluation of numerous state weatherization programs under WAP showed that benefit-cost ratios increased on the order of 80 percent between 1989 and 1996, due to more complete audits and better and more effectively targeted improvements (Berry, Brown and Kinney 1997). Various perspectives of benefits were employed, from one-year savings on energy bills to 20-year returns on societal benefits. In 1996 the average benefit-cost ratio for first year energy savings was 1.79. In the study, all of Washington was included in the "moderate" climate belt, although we have noted earlier that there are considerable differences in climate between eastern and western areas of the state. Table 4.2 shows the average percent reductions in home energy costs for households in the moderate climate region after weatherization. Average benefit-to-cost ratios, depending on the perspective, were 1.2 to 2.7 in this region.

Table 4.2. First-year reduction in home
energy costs (ORNL 1997).

Climate	Electricity		Natural gas	
	Space heating	Total	Space heating	Total
"Moderate" climate	44%	15%	18%	12%

A detailed study of low-income weatherization programs nationwide found that, in general, the more that is invested in weatherizing a dwelling, the greater the savings (Berry and Brown 1996). More importantly, savings were found to be linear with costs over the entire range of the data, with no evidence of diminishing returns.

Aside from weatherization, other low-income energy efficiency measures include installation of compact fluorescent light-bulbs, which use 70 percent less energy than incandescent bulbs; and refrigerator replacement, which can lower electric bills by five hundred to one thousand dollars over the unit's lifetime. The federal Low-Income Home

Energy Assistance Program (LIHEAP), administered by the Department of Health and Human Services, was established in 1980 to reduce the burden of energy costs, to improve health, safety, and comfort, and to prevent termination of energy services. LIHEAP provides block grants to states and other administrative bodies, which in turn apply their own selection criteria within the federal guidelines. Nationally, funding for LIHEAP has declined, from $1.8 billion in 1987 to $1.1 billion in 1999; perhaps not coincidentally, the number of service terminations has doubled since 1988 as well (Pye 1996). Washington's LIHEAP allocation was $21.9 million in 2000, yet this level of funding covered only 17 percent of eligible applicants in the 2000 program year. Allocations for fiscal year 2001 were $28.1 million. Basic energy assistance and crisis assistance account for approximately 70 percent of appropriated LIHEAP funds described in the Washington State Plan for fiscal year 2002 (WOCD 2001), while 15 percent of funds will support weatherization efforts. While a full cost-effectiveness analysis of low-income energy efficiency programs in Washington is beyond the scope of this report, many of these programs nationwide have been shown to be cost effective (Pye 1996).

For a given level of heating, cooling, lighting or appliance usage, the more efficient the home the less the expenditure on energy. In this respect, low-income households benefit from having more disposable income, as do all households. But low-income households derive a broader set of benefits from a reduced energy burden, and benefits from greater energy efficiency for low-income households rebound to society as well (Brown, Berry and Kinney 1994).

The broader benefits to households include increased comfort and health, appliance safety, reduced loss of service from termination, and increased value to property owners. Some of the cost savings from energy efficiency may be reinvested in increased usage; for example, if a residence is better insulated so as to increase the energy efficiency of air conditioning, the household may spend the same amount as previously on air conditioning, but have more comfort.

The benefits to society and to utilities include reduced arrearages, and other transaction costs, reduced public expenditures (including health, fire, building inspection, unemployment insurance, homeless shelters, and housing programs), and an improved local economy, as low-income households tend to spend their discretionary dollars

locally, while most energy expenditures are transferred outside the community (Howat and Oppenheim 1999).

CHAPTER FIVE
CONCLUSIONS

Our analysis shows that improvements in energy intensity – controlled for exogenous factors like price, industrial mix and capital expenditures – are associated with important economic and environmental benefits for Washington and its citizens from 1977 to 1997. It is possible that these benefits can continue into the future. These benefits occurred in the presence of investment in energy efficiency programs by the government, the private sector, and state residents. Further research is necessary to describe the specific link between mandated government or voluntary private energy efficiency programs and improvements in energy intensity in the state.

Past evaluations of energy efficiency programs targeted at the commercial and industrial sectors indicate that the programs can be directly responsible for energy savings. We have shown that claimed savings of commercial and industrial energy efficiency programs have provided a positive return on utility investment assuming that this return has been revealed in our controlled analysis of changes in energy intensity, and that our limited data on utility investment and savings are indicative of the wider range of utility conservation programs. Future programs that have similar success rates as their predecessors would likely result in continued economic benefits to the state.

In addition, we have demonstrated benefits of energy efficiency for Washington households—particularly for low-income households in eastern Washington. Energy efficiency programs that focus on residential consumers can directly increase both net income and quality of life for those consumers.

The future of energy consumption, prices, and intensity remains uncertain, particularly in light of increasing demand throughout the West and restructuring in the retail and wholesale energy industry. Yet, with the decreasing relative contribution of hydroelectric power in the state's fuel mix, the analysis here suggests that greater energy efficiency has had, and may continue to have, a positive effect on the Washington economy. Together, targeted energy efficiency programs in commercial, industrial and residential sectors have the potential to continue to provide benefits to the state, and remain a cost-effective option for meeting Washington's increasing energy demand.

Specifically, how these various programs affect aggregate energy intensity remains a subject of further research.

APPENDIX

This appendix summarizes the quantitative results of our analysis of economic impacts of changes in commercial and industrial energy intensity. This study employs a methodology used in a previous RAND study that examined the public benefit of energy efficiency to the state of California (Bernstein et al 2000). We refer the reader to that study for more detailed discussion of the theory behind the methodology.

Empirical Specification

We consider the following regression specification:

$$EI_{it} = \beta_1 P_{it}^e + \beta_2 EM_{it} + \beta_3 K_{it} + \beta_4 C_{it} + \lambda_i + v_t + \varepsilon_{it} \tag{1}$$

where i indexes states, t indexes time, and the variables are all in log form and defined as follows:

EI   Energy intensity in the industrial sector taking the form E_{it}/Y_{it}, where E is energy consumption and Y represents industrial output (10^3 Btu/\$).[11]

P^e Real energy prices in the industrial sector (\$/10^6 Btu).

EM   Proportion of industrial output accounted for by energy-intensive manufacturing. In the regression results below non-mining manufacturing intensity (*Manufacturing*) and mining-intensity (*Mining*) are allowed to have separate effects.[12]

K   New capital expenditures (buildings and equipment) in the industrial sector ($\$10^6$)

C   An index of heating and cooling days.

λ A state fixed effect.

v A time fixed effect.

Our approach is to use energy intensity directly as a proxy for energy efficiency. To be concrete, consider the following model of gross state product (GSP):

$$\Delta_t \ln GSP_{it} = \alpha_0 + \Delta_{t-1} \ln EI_i \alpha_1 + \Delta_{t-1} \ln P_i^e \alpha_2 + \Delta_{t-1} \ln EM_i \alpha_3 + \Delta_{t-1} \ln K_i \alpha_4 + \\ \Delta_{t-1} \ln C_i \alpha_5 + \Delta_t \ln X_i \alpha_6 + \lambda_i + v_t + \varepsilon_{it} \tag{2}$$

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[11] All economic variables are deflated using the Producer Price Index for Finished Goods, with base year 1982.

[12] Energy-intensive manufacturing industries include mining (30000), stone, clay, and glass (51320), primary metals (51330), paper products (52260), chemicals (52280), and petroleum products (52290).

where Δ_t denotes first differences between periods t and $t\text{-}1$ (e.g., $\Delta_t \ln GSP_{it} = \ln$

$GSP_{i,t}\text{--}\ln GSP_{i,t\text{-}1}$) and $\Delta_{t\text{-}1}$ denotes first differences between periods $t\text{-}1$ and $t\text{-}2$. The

variables in the model are defined as follows:

GSP   Per capita gross state product ($\$10^6$).

EI   A vector of energy intensity variables taking the form E_{ijt}/Y_{ijt}, where E_j represents the energy consumption in sector j (industrial, commercial, and transportation) in Btus and Y_j represents the output of that sector (10^3 Btus/$\$$).

P^e A vector of real energy prices in the industrial, commercial, and transportation sectors ($\$/10^6$).

EM   Proportion of industrial output accounted for by energy-intensive manufacturing (*Manufacturing* and *Mining*).

K   A vector of new capital expenditures in the industrial sector (*new capital*, $\$10^6$) and stock of commercial building square footage (*Building*, ft^2).

C   An index of heating and cooling days.

X   A vector of additional covariates typically included in cross-state growth regressions—proportion of the population of working age (18-65), proportion of the population with a college-level education or more, service share of output, and government expenditures as a fraction of total output.

λ A state fixed effect.

v A time fixed effect.

This specification follows a large literature on the determinants of economic growth.[13] It argues that per capita state economic growth is correlated with both the stock and flow of capital and labor, their quality, and governmental policies. The inclusion of state fixed effects accounts for differences in initial economic conditions and governmental policies (separate from expenditures) that affect economic growth. Time fixed effects control for business cycle effects common to all states.

Results

Table A.3 presents our baseline regression results of the effect of changes in the growth rate of industrial and commercial energy intensity on state economic growth. The coefficients on industrial and commercial energy intensity (–0.023 and –0.017) indicate that GSP growth rises as state economies become less energy intensive. These estimates

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[13] Standard references include Solow (1957), Dennison (1962), Barro and Sala-i-Martin (1995), Griliches (1998), and Jorgenson, Gollop, and Fraumeni (1987). See Crain and Lee (1999) for a review of the empirical literature on the determinants of U.S. state economic growth.

tells us that a ten percent increase in the rate of growth in industrial energy intensity, for example, leads to a 0.23 percent decline in the rate of state economic growth. The remaining covariates in the model generally have signs and magnitudes consistent with the literature on state economic growth. One exception is the coefficient estimate on *new capital*. Investment is generally thought to be the cornerstone of economic growth, and so it is somewhat puzzling that *new capital* is statistically insignificant. This is at odds with the literature on economic growth in general, although the measurement of industrial capital is generally difficult and the particular measure used here is different from those employed in other studies of state economic growth.[14] Also, as noted above, the effect of any measurement error in this variable, which tends to bias the coefficient toward zero, will be exacerbated using first differences and state fixed effects. Note that the addition of new commercial buildings, a variable that is easier to quantify than industrial capital, has the expected sign and is of a substantial magnitude.

Although, at first glance, these coefficients appear small, their cumulative effects on the level of state GSP over time can be quite large. This is because growth is an exponential process. Table A.4 illustrates the predicted effect of energy intensity on state economic growth using data on GSP and energy intensity averaged across the 48 states in our analysis. The first three columns list the mean values of *Ind. EI*, *Com. EI*, and per capita GSP. The final column estimates what per capita income would have been had there been no change in energy intensity between 1977 and 1995.[15] Actual per capita GSP in 1997 was $22,363 (1982$)[16]. Had there been no change in energy intensity, the model predicts per capita GSP in 1997 would have been $21,746. Thus, we can conclude that the decline in industrial and commercial energy intensity between 1977-95 increased per capita income in 1997 by 2.84 percent, or $617 ($806 in 1998$). Considering the size of the U.S. population, by these estimates, the decline in energy intensity made a significant contribution to aggregate welfare over this period. Table A.4, also presents 95

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[14] See, for example, Munnell (1990) and Holtz-Eakin (1993) who construct their own state series on capital accumulation.

[15] Because the data are first differenced and lagged one period we lose two years of data.

[16] Except as otherwise noted, results are generally reported in real 1982 dollars (1982$) in this appendix; 1998 dollars (1998$) are reported in the body of this report.

percent confidence intervals around the predicted effect of energy intensity on GSP.[17] Note that this interval widens as we deviate further from the mean value of *Ind. EI* and *Com. EI* (27.56 and 5.28). In 1997, the 95 percent confidence interval lies between $797 and $816 (1998$).

Results for Washington

The energy intensity coefficients estimated previously represent average effects over the 48 states in the analysis. It is entirely plausible that the effect of energy intensity on economic growth in Washington deviates from this average. Unfortunately, we do not have sufficient data to produce these coefficients separately for Washington. One approach, then, is simply to apply the energy intensity coefficients estimated for the entire sample to data from Washington.

The first three columns in Table A.5 list the mean values of *Ind. EI*, *Com. EI*, and per capita GSP for Washington. As in Table A.4, the fourth column estimates what per capita income would have been had there been no change in energy intensity between 1977 and 1997 assuming energy intensity has the same effect in Washington as it does on average in the other states in our sample. Actual per capita GSP in Washington in 1997 was $23,859 ($1982). Had there been no change in energy intensity, the model predicts per capita GSP in 1997 would have been $23,232 (1982$). By this estimate, the decline in industrial and commercial energy intensity between 1977-97 increased per capita income in 1997 in Washington by 2.70 percent, or $627 ($819 in 1998$). Again, since the change in energy intensity in Washington deviates from the average change in the entire sample used to calculate $\hat{\alpha}_1$, we generate 95 percent confidence intervals around the predicted effect of energy intensity on GSP as we did above in Table A.4. These bounds are presented in columns five and six. These estimates imply that the decline in energy intensity in Washington increased per capita income by between $789 and $850 in 1997 (1998$).

A second approach is to group states with similar characteristics together and estimate the model separately for each group. The coefficient estimates then presumably

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[17] We approximate this interval as $\hat{y}_j \pm 2\left[\hat{\sigma}^2 X_j (X'X)^{-1} X'_j\right]$.

reflect the unique circumstances of those states. We experiment with three different categorizations that divide the sample into quartiles based on industrial intensity (i.e., percentage of GSP accounted for by industrial output), industrial energy prices, and climate. We also divide states into those with no, weak, and strong building codes and by Department of Energy (DOE) region (10 regions).[18] The trouble with this approach, of course, is that by dividing the sample into groups our coefficient estimates are derived from substantially smaller samples and so are generally less precisely estimated. Also, it is possible that by grouping states in one dimension, we may also group them by some other unknown dimension that could have unpredictable effects on the coefficient estimates.

Table A.6 presents the industrial and commercial energy intensity coefficients for the group of states in which Washington falls for each of these five categorizations.[19] The only estimates that seem to tell a consistent story are those based on industrial intensity. We would expect that changes in industrial energy intensity would have less of an effect on GSP in states with relatively low industrial intensity. This is indeed what we see in the data. States in the first quartile of industrial intensity, like Washington, have a relatively small and imprecisely estimated coefficient on *Ind. EI* and relatively large coefficient on *Com. EI*. This is reversed in states in the fourth quartile of industrial intensity (not shown)—they have a relatively large coefficient on *Ind. EI* and relatively small coefficient on *Com. EI*. The other categorizations do not yield any discernable pattern in the coefficient estimates.

Table A.7 assumes that the coefficient estimates generated by states in the first quartile of industrial intensity are representative of the effect of industrial and commercial energy intensity on GSP in Washington. By these estimates, the decline in industrial and commercial energy intensity between 1977-95 increased per capita income in 1997 in Washington by 3.7 percent, or roughly $857 ($1120 in 1998$). The 95 percent confidence interval for this estimate lies between $1056 and $1183 in 1997 (1998$).

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[18] See Ortiz and Bernstein (1999) for a listing of states by type of building code.

[19] Washington is in the first (i.e., lowest) quartile of states by industrial intensity and climate and the fourth quartile of states by industrial energy prices. It is in DOE's West region and among states with strict building codes.

The Value of Energy Intensity to the Washington Economy

To estimate the value of improvements in energy intensity to the Washington economy, we start with the expression used in the regression (2), rewritten as:

$$\Delta_t \ln GSP_t = \alpha_t' + \Delta_{t-1} \ln EI_{ind}\alpha_{ind} + \Delta_{t-1} \ln EI_{comm}\alpha_{comm}$$

where GSP_t is the gross state product, α_t' is the growth rate of state product in the year t due to all causes except changes in energy intensity, EI_{ind} and EI_{comm} are the industrial and commercial energy intensities, respectively, and α_{ind} and α_{comm} are the coefficients relating changes in energy intensity to changes in the rate of growth of state product.

For the period 1977 to 1997, we have data on the gross state product and the industrial and commercial energy intensities. Using values of the coefficients α_{ind} and α_{comm} obtained from the regression analysis, we can calculate, α_t', the growth due to factors other than changes in energy intensity. We can then estimate what the state gross product would have been if energy intensity had not improved from 1977 through 1997, by writing

$$\Delta_t \ln GSP_t' = \alpha_t'$$

where the estimate of what gross product would have been without energy intensity improvements depends on our estimates of the impact of energy intensity, as represented by the coefficients α_{ind} and α_{comm}.

The value of the changes in energy intensity that did occur, measured in terms of impacts on state gross product, are thus given in each year t by

$$\text{Value of changes energy intensity}_t = GSP_t - GSP_t'$$

This estimate depends on our estimates of the coefficients α_{ind} and α_{comm}. Since there is uncertainty in these estimates, we calculate a range of estimates for the value of changes in energy intensity corresponding to our range of estimates for the coefficients.

We can similarly estimate the value of improvements in energy intensity by making forecasts of future growth in gross state product and future trends in energy intensity. Forecasts of each of these factors are available from a variety of sources, but the one thing we know for certain about forecasts is that they are generally wrong.

Rather than use a single forecast, we will thus use past trends to create an ensemble of forecasts and calculate the value of changes in energy intensity across this ensemble.[20]

To calculate an ensemble of future growth rates of gross state product due to factors other than changes in energy intensity, we estimate future values of α_t' from its past trends. This growth rate has waxed and waned between 1977 and 1997, with recessions in the early 1980s and 1990s, interspersed with periods of rapid growth. We calculate high, low, and medium estimates for α_t' of 3.24 percent, 2.41 percent, and 1.17 percent by calculating the average growth rates over the periods 1985 to 1997, 1977 to 1997, and 1977 to 1985.

Similarly, we calculate an ensemble of scenarios of future trends in energy intensity, as shown in Figure 3.2, by projecting the average rate of change over the 1985 to 1997, 1977 to 1997, and 1977 to 1985 periods, out into the future.

For each combination of forecasted energy intensity trends, state gross product due to factors other than changes in energy intensity, and estimates of the impacts of changes in energy intensity, we can then estimate the future value of the energy intensity using the same formula as we used to estimate the past value.

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[20] The American Heritage dictionary defines ensemble as a unit or group of complementary parts that contribute to a single effect. Our use of the term here is meant to signify that a single forecast is much less valuable than a range of scenarios employed towards a common purpose.

Tables and Figures

Table A.1. U.S. and Washington Industrial
and Commercial Energy Intensity (10^3
Btus/$1982): 1977-1997

Year	U.S.		Washington	
	Ind.	Com.	Ind.	Com.
1977	31.13	6.40	39.01	5.01
1978	29.30	6.24	37.03	5.00
1979	30.21	6.32	34.61	5.21
1980	30.40	6.47	39.13	5.59
1981	28.66	6.26	42.53	6.53
1982	28.07	6.29	39.16	6.68
1983	27.95	5.96	39.69	6.13
1984	27.06	5.86	41.05	5.82
1985	26.34	5.49	37.43	6.03
1986	26.30	5.08	34.29	5.08
1987	26.27	4.95	34.56	5.02
1988	26.13	5.00	34.20	5.03
1989	26.69	4.99	32.00	4.70
1990	27.08	4.90	32.49	4.47
1991	27.93	4.81	33.78	4.26
1992	28.70	4.46	32.71	3.93
1993	28.04	4.42	30.68	3.87
1994	26.62	4.28	29.86	3.69
1995	25.85	4.21	31.61	3.67
1996	25.33	4.31	29.15	3.73
1997	24.63	4.14	28.21	3.41

Table A.2. The Determinants of Industrial
and Commercial Energy Intensity

	Ind. EI		Com. EI	
	Coef.	Std. Err.	Coef.	Std. Err.
P^e	-0.687	0.085	-0.045	0.071
Manufacturing	0.276	0.041	—	—
Mining	0.060	0.170	—	—
New capital	-0.014	0.021	—	—
Building	—	—	-0.152	0.069
Climate	0.242	0.135	0.553	0.110
	Observations: 1008	R-Squared: 0.933	Observations: 1008	R-Squared: 0.872

Notes: All variables are in logs. Regressions include state and time fixed effects. Standard errors are corrected for heteroscedasticity.

Table A.3. The Effect of Energy Intensity
on Per Capita State Economic Growth:
1977-1997

	Coef.	Std. Err.	95% confidence interval	
Industrial Energy Intensity	-0.023	0.006	-0.036	- -0.011
Commercial Energy Intensity	-0.017	0.008	-0.032	- -0.002
Transportation Energy Intensity	0.003	0.011	-0.019	- 0.025
Industrial Energy Prices	-0.011	0.009	-0.027	- 0.006
Commercial Energy Prices	-0.034	0.008	-0.050	- -0.017
Transportation Energy Prices	-0.001	0.020	-0.041	- 0.039
Manufacturing GSP	-0.011	0.006	-0.022	- -6.7E-05
Percent of Industrial GSP from Mining	0.008	0.003	0.002	- 0.015
New Capital Expenditures	8.7E-07	4.1E-07	5.9E-08	- 1.7E-06
New Building Stock	0.186	0.066	0.057	- 0.315
Climate	0.013	0.009	-0.005	- 0.032
Population Age 18-64	1.123	0.156	0.816	- 1.430
Population Bachelors	-0.003	0.005	-0.014	- 0.007
Percent GSP from Government	-0.329	0.034	-0.396	- -0.263
Percent GSP from Service	-0.741	0.052	-0.844	- -0.638

Observations: 912   R-Squared: 0.900

Notes: All variables, except *new capital* are in logged first differenced form. See text for variable definitions. Regression controls for state and year fixed effects. Standard errors are corrected for heteroscedasticity across panels.

Table A.4. Predicted Effect of Industrial
and Commercial Energy Intensity on State
Per Capita GSP: National Average, 1979-
1997

Year	Δ_{t-1} ln *Ind. EI*	Δ_{t-1} ln *Com. EI*	Actual per capita *GSP*	State Per capita GSP given no change in *Ind. EI* or *Com. EI*	Lower-bound effect	Upper-bound effect
1979	-0.065	-0.023	13,811	13,773	13,760	13,786
1980	0.029	0.003	13,200	13,103	13,097	13,108
1981	0.013	0.026	13,450	13,321	13,315	13,327
1982	-0.067	-0.034	13,299	13,162	13,148	13,175
1983	-0.023	0.007	13,794	13,685	13,681	13,689
1984	-0.006	-0.058	14,988	14,820	14,808	14,832
1985	-0.042	-0.024	15,721	15,502	15,492	15,512
1986	-0.025	-0.067	16,492	16,227	16,210	16,243
1987	-0.030	-0.077	17,186	16,843	16,823	16,863
1988	-0.011	-0.020	18,012	17,606	17,600	17,612
1989	-0.012	0.002	18,072	17,665	17,663	17,668
1990	0.023	-0.002	18,032	17,635	17,630	17,640
1991	0.021	-0.017	18,140	17,763	17,757	17,770
1992	0.032	-0.019	18,723	18,354	18,346	18,363
1993	0.022	-0.075	19,287	18,896	18,875	18,917
1994	-0.017	-0.010	20,279	19,847	19,842	19,852
1995	-0.053	-0.029	20,823	20,331	20,314	20,347
1996	-0.022	-0.013	21,271	20,733	20,726	20,740
1997	-0.021	0.018	22,363	21,746	21,738	21,753

Notes: Estimates assume a constant marginal effect of *Ind. EI* of –0.023 and *Com. EI* of –0.017 on GSP growth. See text for derivation of lower- and upper-bound effects. All figures are in $1982.

Table A.5. Predicted Effect of Industrial
and Commercial Energy Intensity on Per
Capita GSP: Washington, 1979-1997

Year	Δ_{t-1} ln *Ind. EI*	Δ_{t-1} ln *Com. EI*	Actual per capita GSP	Washington Per capita GSP given no change in *Ind. EI* or *Com. EI*	Lower-bound effect	Upper-bound effect
1979	-0.052	-0.017	15,454	15,431	15,420	15,442
1980	-0.068	0.042	14,290	14,210	14,193	14,226
1981	0.123	0.070	14,174	14,151	14,123	14,178
1982	0.083	0.156	14,201	14,243	14,206	14,281
1983	-0.083	0.023	14,964	14,967	14,951	14,983
1984	0.013	-0.087	15,782	15,745	15,726	15,765
1985	0.034	-0.052	16,170	16,127	16,113	16,141
1986	-0.092	0.036	17,510	17,386	17,365	17,406
1987	-0.088	-0.171	18,192	17,964	17,914	18,014
1988	0.008	-0.011	19,088	18,827	18,823	18,830
1989	-0.010	0.000	19,429	19,156	19,153	19,159
1990	-0.066	-0.067	19,935	19,596	19,570	19,622
1991	0.015	-0.051	20,093	19,742	19,726	19,757
1992	0.039	-0.049	20,655	20,288	20,270	20,305
1993	-0.032	-0.080	21,146	20,722	20,695	20,748
1994	-0.064	-0.016	21,887	21,399	21,381	21,417
1995	-0.027	-0.048	21,806	21,288	21,270	21,305
1996	0.057	-0.004	22,386	21,874	21,858	21,889
1997	-0.081	0.017	23,859	23,232	23,209	23,255

Notes: Baseline estimates assume a constant marginal effect of *Ind. EI* of -0.023 and *Com. EI* of -0.017 on GSP growth. See text for derivation of lower- and upper-bound effects. All figures are in $1982.

Table A.6. The Effect of Industrial and
Commercial Energy Intensity on
Washington's Rate of Economic Growth:
Sensitivity Analysis

Group	Ind. EI		Com. EI	
	Coef.	Std. Err.	Coef.	Std. Err.
Low industrial intensity	-0.020	0.015	-0.054	0.019
Low industrial energy prices	-0.027	0.014	-0.008	0.019
Mild climate	-0.037	0.014	-0.014	0.017
Strict building codes	-0.016	0.022	-0.007	0.043
West DOE region	-0.034	0.010	-0.009	0.013

Notes: Regressions control for all covariates listed in Table A.3. See text for explanation of groupings. Standard errors are corrected for heteroscedasticity across panels.

Table A.7. Predicted Effect of Industrial
and Commercial Energy Intensity on
Washington Per Capita GSP: Alternative
Coefficient Estimates.

Year	Δ_{t-1} ln *Ind. EI*	Δ_{t-1} ln *Com. EI*	Actual per capita *GSP*	Per capita GSP given no change in *Ind. EI* or *Com. EI*	Lower-bound effect	Upper-bound effect
1979	-0.052	-0.017	15,454	15,424	15,393	15,454
1980	-0.068	0.042	14,290	14,230	14,200	14,260
1981	0.123	0.070	14,174	14,202	14,124	14,280
1982	0.083	0.156	14,201	14,373	14,266	14,479
1983	-0.083	0.023	14,964	15,119	15,087	15,151
1984	0.013	-0.087	15,782	15,857	15,809	15,904
1985	0.034	-0.052	16,170	16,209	16,180	16,237
1986	-0.092	0.036	17,510	17,500	17,459	17,540
1987	-0.088	-0.171	18,192	17,977	17,834	18,119
1988	0.008	-0.011	19,088	18,833	18,826	18,840
1989	-0.010	0.000	19,429	19,163	19,157	19,169
1990	-0.066	-0.067	19,935	19,560	19,485	19,636
1991	0.015	-0.051	20,093	19,668	19,633	19,703
1992	0.039	-0.049	20,655	20,174	20,141	20,207
1993	-0.032	-0.080	21,146	20,549	20,476	20,622
1994	-0.064	-0.016	21,887	21,212	21,165	21,260
1995	-0.027	-0.048	21,806	21,067	21,017	21,116
1996	0.057	-0.004	22,386	21,639	21,604	21,674
1997	-0.081	0.017	23,859	23,002	22,954	23,051

Notes: Baseline estimates assume a constant marginal effect of *Ind. EI* of –0.022 and *Com. EI* of –0.045 on GSP growth. See text for derivation of lower- and upper-bound effects. All figures are in $1982.
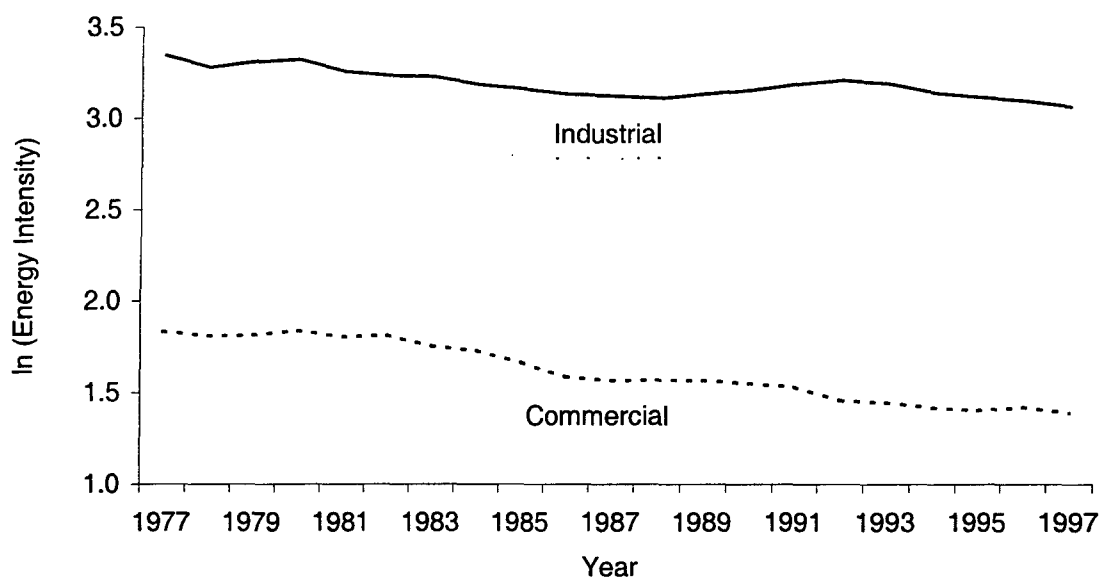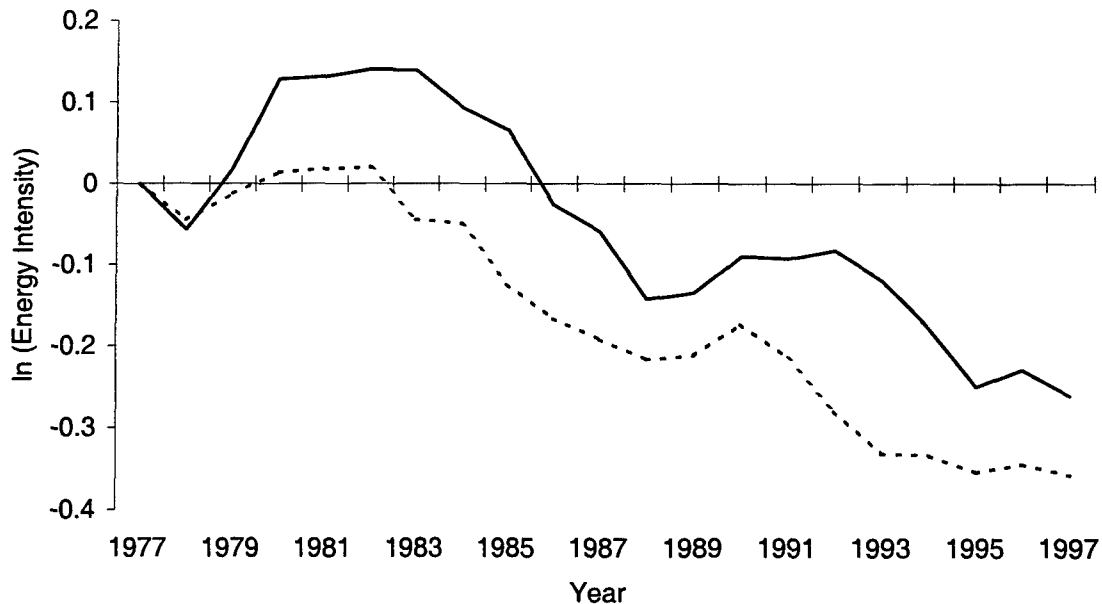
Figure A.1. U.S. energy intensity:
1977-1997.

Figure A.2. U.S. energy intensity fixed-
effect coefficients relative to
1977 energy intensity.

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